ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. III OCTOBER–NOVEMBER, 1908 No. 7

THE SHALE OIL INDUSTRY OF SCOTLAND.

D. R. STEUART, F.I.C.

NATURE OF THE INDUSTRY.

Shale is mined in much the same manner as coal, and after being broken into small pieces by machinery, is distilled in retorts and gives as products crude oil, ammonia water and fuel gas. The crude oil extracted from a ton of shale varies from 16 to 35 gallons, and the ammonium sulphate 30 to 70 pounds. The refined products of the crude oil are spirit or naphtha 4 per cent., burning oil 33 per cent., gas oil 7 per cent., lubricating oil 20 per cent., solid paraffin 10 to 12 per cent.

The manufacture is allied to the great petroleum industry; only, instead of obtaining the crude oil by boring for it and applying pumps where necessary, as in the United States, Russia and elsewhere, the shale has to be mined at much expense and retorted to procure the crude oil. The rapid and violent method of the retort gives a much coarser crude oil than the gentle age-taking processes of nature used in creating petroleum; so that besides the extra expense in producing the shale oil there is extra difficulty and expense in refining it. Petroleum often requires only one distillation as far as lamp oil is concerned, and after a slight treatment with sulphuric acid and soda it is ready for the market. The burning oil from shale requires three or four distillations and chemical treatments, and the proportion of chemicals required is heavy. One advantage that the repeated distil-

lations give is the opportunity afforded for making better fractionated and more homogeneous products.

In a petroleum refinery the stills, being very large, are few and there is not much plant to be seen, the tanks being often under ground. In a Scotch oilworks there are the great benches of shale retorts sometimes over 60 feet high, with the great stacks of numerous series of 3-inch pipes, 30 or 40 feet high for air condensers. There is the 3-story-high sulphate of ammonia house, with its high column-stills, the acid saturators for the ammonia, vacuum or other evaporator for the sulphate from the recovered sulphuric acid of the refinery, centrifugal driers, storing bins, grinding mills, etc. In the refining department the stills are small and, on account of the repeated distillations, very numerous; the washers for vitriol and soda many; there are coolers, refrigerators, filter and hydraulic plate presses for the separation of the heavy oil and solid paraffin; great sweating houses for the paraffin refining; candle works; sulphuric acid making and concentrating; acid-recovery plant; engineers', joiners' and plumbers' shops, etc.—a very large and varied collection of apparatus covering much ground; so that for a comparatively small production there is a very large and expensive plant. A conspicuous feature of oilworks is the great hills of spent shale.

EXTENT OF THE INDUSTRY.

There are at present only seven paraffin oil works in Scotland. Three are smaller and produce only crude oil and ammonia. Four are larger and have fully equipped refineries. Two of them have candle works attached. Together they distil more than two and one-half million tons of shale in a year.

In 1906,

West Lothian or Linlithgowshire produced	1,791,836 tons shale.
Mid Lothian or Edinburghshire produced	732,635 tons shale.
Lanarkshire	21,051 tons shale.
Total	2,545,582

In 1906 the refined products were:

Spirit or naphtha, sp. gr.....680 to .750,	about 2½ millions imperial gallons.
Burning oils, sp. gr..... .790 to .830,	about 17 millions imperial gallons.
Gas or intermediate oils, .850 to .870.....	about 38,000 tons.
Lubricating oils, .865 to .900.....	about 40,000 tons.

Solid paraffin wax, m. pts., 100° to 130° F.....	about 22,500 tons.
Sulphate of ammonia, over.....	50,000 tons.
Still coke, selling 60 to 70 shillings a ton.....	5,000 tons.

The total paid up capital of the four refining companies is about one and one-half million pounds sterling. The dividends last year were 5, 15, 15, and 50 per cent., respectively; for this year 7, 15, 17.5 and 50 per cent.; but many years the dividend for most works was *nil.* The wages paid by the companies are about £700,000 a year. There are 8,300 men employed, including 3,380 miners.

The whole industry is small in comparison with the mineral oil requirements of the country, nevertheless it is large enough to cause the light of the common people to be supplied at less than one-half the price that would have had to be paid if dependent on foreign kerosene only.

ORIGIN OF THE INDUSTRY.

James Young (born 1811) started life assisting his father as a cabinet-maker in Glasgow. He attended lectures on chemistry given by the great Professor Thomas Graham, showed aptitude, and became Graham's assistant for seven years. He followed Graham to London when he was appointed to the professorship at University College. By and by Young became manager for four and one-half years in Muspratt's chemical works, near Liverpool. He afterwards held an appointment for many years in Tennant's chemical works, Manchester. While there he was written to by Professor Lyon Playfair (afterwards Sir Lyon and Lord Playfair) telling him of a spring of petroleum in a coal pit at Alfreton, Derbyshire, which he suggested Young should erect works to refine. Young did so, starting, I suppose, the first petroleum works of present day type. The crude oil was of the consistency of thin treacle, and the quantity about 300 imperial gallons a day; and from it was manufactured illuminating and lubricating oils. Solid paraffin in small quantity was extracted and made into candles. This was in 1848. Within two years the oil began to fail. The mode of its occurrence had suggested to Mr. Young that it had been extracted from the coal

by a subterranean low-temperature distillation, and he set himself to make a similar oil artificially. He tried many coals of England and Scotland until he discovered the Torbanehill or Boghead gas coal (see p. 584). This substance gave him the products he wanted. He took out patents for the low-temperature distillation of coal both in Britain and the United States; and in partnership with Mr. Meldrum, who had managed for him at Alfreton, and with Mr. E. W. Binney, of Manchester, the geologist, who supplied the capital, works at Bathgate were started in 1850. During the next ten years works were erected at various places in the United States to distil coal or shale by this method, some with license from Young, and his method of refining by fractional distillation from stills and treatments with sulphuric acid and with soda became well known; so that when after 1859 petroleum became plentiful, the method was familiar, and works suitable for its refining were already in existence and at hand. During those years great interest in bitumens and bituminous minerals was being taken in America and all over the world and many investigators were in the field, and modern works and methods could not have been long delayed, nevertheless James Young stimulated thought in America, introduced suitable petroleum lamps, and helped at once to give things a right direction; and he has some claim to be considered the father not only of the Scottish paraffin oil manufacture but also of the great petroleum industry of America.

James Young amassed a fortune, which his genius and enterprise deserved; bought estates in several parts of Scotland, among others, Kelly in Renfrewshire on the Frith of Clyde. He received the honorary degree of LL.D. from St. Andrews University, was an original member of the Chemical Society, and F.R.S. of London. He died in May, 1883. He invented the method of making chlorate of potash, etc. He was a great friend of David Livingstone, the African traveler, who laid the foundation stone of Addiewell works for Dr. Young.

THE MINERALS USED.

The Torbanehill mineral was used for about twelve years in Scotland for paraffin oil manufacture. Some was exported to the continent of Europe and to America for the same purpose. After that time it soon became exhausted. Shale was started early in the sixties and has continued ever since. Gas and parrot coals were also used. Throughout the Coal Measures there were many bands of shale, and often in connection with coal seams. Above the coal seam there was often a thin bed of shale, and under the coal a thin bed of black-band ironstone. Shale seams were worked in the Clyde valley coal field in connection with the Splint and Virtuewell coals, the mussel-band ironstone, and the Kiltongue coal. In Fife, Midlothian, Lanarkshire, Stirlingshire, Renfrewshire and Ayrshire, shale and bastard parrot coals were worked in the Coal Measures, Millstone Grit, and Mountain Limestone. In the early and bright days of the industry shale or gas coal was worked for oil at various places in the English coal fields also, for instance, in Yorkshire, Cheshire, Lancashire, Staffordshire and especially Flintshire in North Wales. In Flint the Leeswood cannel seam was from five to six feet thick, of a limited basin-shaped area, and it thinned at the edge. All have been stopped for many years. When American petroleum was imported in large quantity the prices of products fell, the richer cannel coals were used only for gas making, and the bastard parrot coals and shales of the Coal Measures, both in England and Scotland ceased to be mined; so that for many years now the manufacture has been confined to the shales of the calciferous sandstone (see p. 587).

LOCALITY OF THE INDUSTRY.

The locality of the industry may be appreciated from the map, Fig. 53, on the following page.

The middle of the shale field lies thirteen miles due west of Edinburgh. It is a strip of country five to eight miles wide, stretching from the shores of the Frith of Forth north of this point southward for sixteen miles. It passes through the counties of West Lothian and Mid Lothian and ends within the borders of Lan-

narkshire, near the western termination of the Pentland Hills. It contains the shale-working districts of Dalmeny, Philpstoun, Winchburgh, Uphall, Broxburn, Mid-Calder, West Calder and Tarbrax. The accompanying map shows the location of the district and also of the areas of the calciferous. Oil shale beds are found, although not at present worked, in a narrower strip farther east, and not long ago there was an oil work on it near

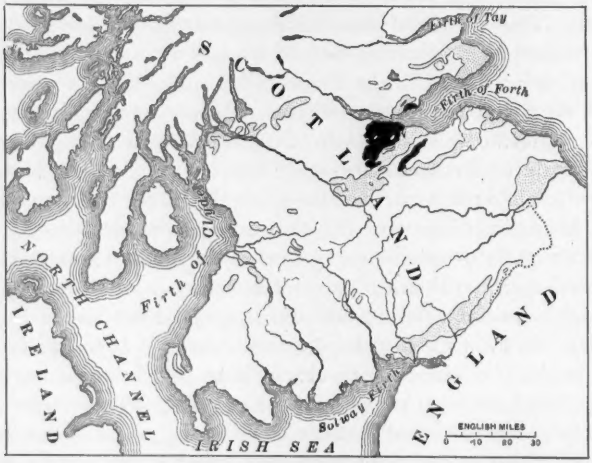


FIG. 53. Map of the south of Scotland, with calciferous sandstone shown darkened and the shale field black.

the village of Pentland. A limited continuation of this band is found beyond the Forth in Fife at Burntisland and here also an oil works was in operation fifteen years ago or so. These districts may yield some oil shale in the future. The accompanying section, Fig. 62, page 594, shows the structure of the West Calder shale field. A series of columnar sections taken at different points is given in Fig. 54, page 579.

HISTORY.

The first oil work starting in 1850, there were about 6 in 1860, 90 in 1870, 26 in 1880, 14 in 1890, 9 in 1900, 7 in 1908.

The first government statistics of shale were taken in 1873, 23 years after the start of the manufacture. We give the annual output in Scotland, and, for the sake of space, selecting only every tenth year, for comparison.

1873	524,095	tons shale.
1883	1,130,729	tons shale.
1893	1,947,842	tons shale.
1903	2,009,265	tons shale.

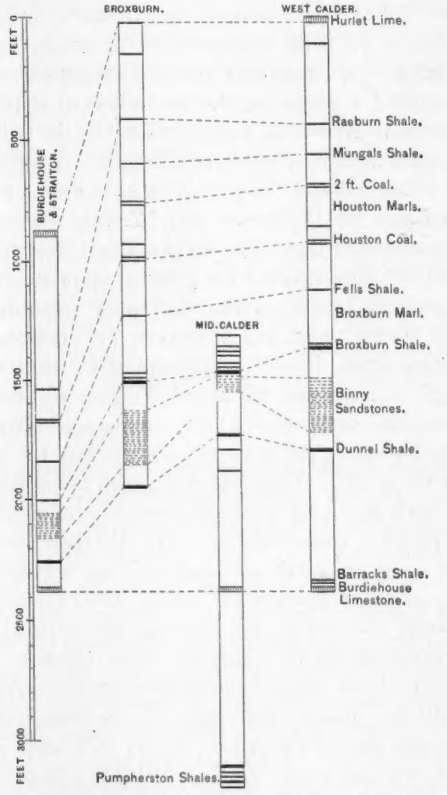


FIG. 54. General section of the West Calder shale field and carboniferous limestone series to the west. (After H. M. Caddel, *Geology of the Oil Shale Fields of the Lothians.*)

Although the number of works was reduced the total production was kept up.

Soon after 1860 American petroleum was imported in large and increasing quantities. At first only lamp oil was imported and the Scots modified their retorts and heats to get a larger proportion of the heavier products. They bought petroleum residuum from America to refine into lubricating oils. Soon the Americans took up the refining of heavy oils for themselves and flooded Britain with it also, and the Scots improved their freezing plant to get more solid paraffin. Soon also solid paraffin was imported in large quantities, and now the retorts were lengthened and suited for increasing the production of sulphate of ammonia. Peruvian guano had long been used by the British farmer as an important source of combined nitrogen. By 1880 it began to become exhausted and the price of sulphate of ammonia rose as high as £24 a ton. This put new life into the industry followed by over-production; also the increased import of nitrate of soda had by 1890 lowered the price of sulphate of ammonia to £8. Ammonia is now produced in large quantities by iron works, coke ovens, mond gas producers, etc., besides combined nitrogen being made from the atmosphere by electrical means, and although America has harnessed Niagara for that purpose, nevertheless, on account of the increasing demands for nitrogenous fertilizers the price of sulphate has for some years kept up to £12 a ton. There has been keen competition also in later years with petroleum products from Russia and Roumania, and solid paraffin from Galicia. The Scottish industry still manages to exist and some companies to pay a handsome dividend. The price of burning oil during the fourteen years of Young's patent was about two shillings and sixpence a gallon; for many years now the price has been about sixpence.

The history of this war of competition records many defeats, many casualties. Every new move of the competitors swept many oil works out of existence. Every new step forward in retorting or refining would bring a temporary hopefulness and new works would start, soon again to be stopped. During the 57 years of the existence of the industry 120 different works have

been thus started and stopped, some without ever paying a dividend. Much capital has thus beeen permanently lost. The companies that have kept in existence have succeeded in doing so by improving methods and plant, but principally by increase of size enabling them to cheapen production by concentration.

RETORTING AND REFINING.

There has been great variety in the form of retort and of condenser tried by the numerous works. The first retort used by James Young was a horizontal one of cast iron, of the shape and size then used for gas-making (see Fig. 55). Horizontal retorts

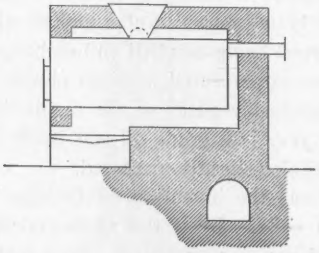


FIG. 55. Horizontal retort.

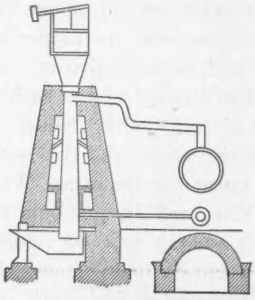


FIG. 56. Old vertical retort.

were used by others in many sizes and shapes; but Young very soon adopted a small vertical retort of circular section, which was luted into a water trough below, from which the spent shale was drawn in small quantity every hour (see Fig. 56). By and by it was fitted with a bell hopper on top, which was charged every hour, alternately with the drawing every half hour. Soon also steam was injected at the bottom and found to be a great improvement both for quantity and quality of the crude oil. Several retorts were heated by one coal fire and, being dependent on the care of men, they were often over-heated, which spoiled the crude oil and destroyed the retort. The distillation was upwards. The steam helped to diffuse the heat through the mass of shale and to sweep the oil vapors rapidly out of the heat, where the valuable solid paraffin and heavy oil tend to deposit carbon

and become decomposed into lighter products. The vertical retorts were increased in size, and oval and other forms were adopted. Some were tried with internal combustion and limited inlet of air but were not successful. William Young tried a double casing, ensuring the gentle heat best for a good crude oil, producing heavy products, solid paraffin and decreased loss in refining. It showed how much could be done in improving the crude oil, but otherwise was a failure.

In 1873 N. M. Henderson invented a retort which, besides giving with precision the gentle heat wanted, also used the spent shale as fuel and thereby reduced the cost of manufacture. Four retorts were erected in one oven over the one furnace; and the spent shale, with its 12 per cent. of fixed carbon, was dropped from each in succession at four-hour intervals and supplied with a limited amount of air; each retort being emptied and recharged every sixteen hours. Steam was superheated in pipes placed in the retort ovens, and the incondensable gases of the distillation were burned in the oven. The very best crude oil was made by this retort, and the ammonia was also slightly increased.

The modern type of retort was the invention of George T. Beilby and William Young, in 1881. By it the ammonia was doubled or more, and much fuel gas was produced. Four metal retorts were connected with a large hopper above (see Fig. 57) common to the four. The distillation was upwards through the cold shale of the hopper where the crude oil was condensed and redistilled. Each retort had an iron upper part where the oil was distilled from the shale at a low temperature. The shale was passed down through the lower part made of firebrick, where it was subjected to as high a temperature as possible without fusing, and acted on by steam. The nitrogen was partly converted into ammonia, and the carbon into producer gas. At intervals in the bench of retorts there was one

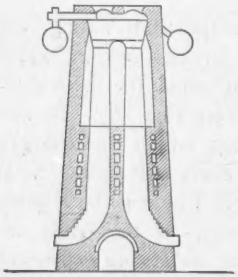


FIG. 57. Young and Beilby retort.

for coal to act as a gas producer to supplement the retort gas, and the ammonia from it was also saved.

The retorts now in operation are on the Young and Beilby principle. I may mention as examples the Bryson retort (see Fig. 58) and the Henderson retort (see Fig. 59). The Bryson is of circular cross-section, the Henderson oblong. Both are continuous working. In the Bryson there is a table below to support the column of shale, with a revolving arm to take the spent shale from the table and keep up the slow movement downwards. In the Henderson the same result is brought about by the slow

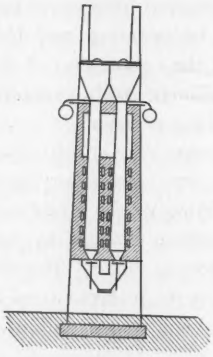


FIG. 58. Bryson retort.

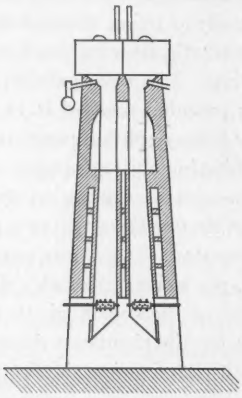


FIG. 59. Henderson retort.

motion of two toothed drums. Henderson increased the length greatly, and, with an ordinary shale, the retort makes more gas than it requires for its own use. From ground level to top of hopper is 63 feet, and 15 tons of shale are in a retort at a time. The metal part of retort is 14 feet long and 2 feet 9 inches by 1 foot 3 inches at the top. The brick part is 20 feet long and 4 feet 8 inches by 1 foot 10 inches at bottom. The throughput per day is four to four and one-half tons of shale.

The distillation of the ammonia water is much the same as in large gas works. A large works may turn out thirty tons of sulphate of ammonia per day.

The refining consists of distillations and treatments. The distillations separate the various products from each other by boiling at different temperatures; and the continuous-working, connected-still system of N. M. Henderson is in general use. The chemicals used in the treatments are oil of vitriol that separates a black tar and caustic soda which also separates a black tar. Distillations and treatments are repeated several times. The amount of oil of vitriol used is about three to four per cent. by volume on the crude oil.

The heavier oils are first cooled naturally and further by freezing machine, and the solid paraffin separated by filter presses, and, generally, further pressed by hydraulic machinery. Both types of ammonia freezing machine are in use, viz., condensed gas and solution. The solid paraffin is refined by sweating, and Henderson's patented method is in use in all the refineries. A little is refined by naphtha pressure. A treatment with cyanide char and filtering through paper is the finishing process.

The cost of mining of the shale varies very much according to the circumstances from 3 to 6 s. per ton. The retorting of the shale costs 1/6 to 2/ per ton. The refining of the crude oil costs ¾ d. per gallon of crude oil. The lordship charged by the proprietor of the soil is 3d. to 10 d. per ton of shale. The stirring tanks for the chemicals do not attain the magnificent sizes of the American refineries, the largest being about 40,000 gallons.

GEOLOGY.

THE TORBANEHILL OR BOGHEAD MINERAL.

This was the first mineral used by Young, Meldrum and Binney. It was found in a small basin a little to the southwest of Bathgate, two or three miles in diameter; and nowhere else in the United Kingdom.

It may be described as consisting of 20 to 30 per cent. of clay mixed with 70 to 80 per cent. of carbonaceous matter. This is insoluble in benzene, turpentine, carbon bisulphide or petroleum spirit, and is therefore not of the nature of petroleum or bitumen, although it gives petroleum-like products by destructive

distillation at 700° or 800° F. The mass of carbonaceous matter seems without structure mingled with stems or roots of trees showing structure, and the fossils were found throughout the bed and not merely on the surfaces of seams, as is general with coal. It contained impressions of *Sigillaria* and *Stigmaria*, and the few inches of fire clay below it contained *Stigmaria*, the *Sigillaria* sometimes proceeding upwards through the torbanite in its natural position when living. There are no fish remains, although these are generally found in Scotch cannel coals. The microscope sometimes showed the scalariform tissue of tree ferns, also the spores of ferns in clusters. Torbanite is no doubt the remains of organic matter in its original position and not a product of distillation, as some have suggested; a distillate would have been soluble in petroleum spirit. Renault considers both torbanite and oil shale to be mainly alteration products of masses of gelatinous fresh-water algæ from which oxygen has been eliminated, and containing immense numbers of bacteria, especially micrococci. In cannel coals the prevailing vegetable constituents are spores of cryptogamic plants, algæ being rare and in many cases absent.

The Torbanehill mineral is of a brown or nearly black color; there were brown and black varieties, and the brown was the richer. It had a yellow or fawn-colored streak without lustre, and subconchoidal fracture, was amorphous, and apparently homogeneous when fresh, but showed distinct stratification when spent in the retort. It was very indestructible and did not deteriorate with weathering. Near basalt dykes it became soft, sticky and brown, resembling melted india-rubber. In the laboratory it takes fire readily when put to a flame, splits, does not fuse, burns with a very smoky flame, giving an empyreumatic odor, and leaving a considerable amount of white ash.

The crude oil taken from it was 90 to 130 gallons per ton; sp. gr. about .890. It was richer in the east part of the field than the west, and it deteriorated somewhat with depth. It yielded 44 to 48 per cent. of crude oil and 1 to 1½ per cent of solid paraffin. It has been analyzed by many chemists.

Heated in a close crucible the mineral gave (Dr. Fyfe):

67 to 70 per cent. volatile hydrocarbons,
6.6 to 16.3 per cent. fixed carbon, and
12.8 to 23.2 per cent. ash.

The following analysis is by Anderson:

Carbon	64.02
Hydrogen	8.90
Nitrogen	0.55
Sulphur	0.50
Oxygen	5.66
Ash	20.32
Total	99.95

Ash: Silica	56.09
Alumina	40.04
Peroxide of iron	3.24
Lime	0.34
Magnesia	0.46
Total	100.17

The sp. gr. varied from 1.17 to 1.316.

It differs from coal in having a larger proportion of hydrogen, and in not leaving a coke on distillation. In ordinary gas coal the proportion of carbon to hydrogen is 100 to 10; with Torbanehill mineral 100 to 14. The geological position was near the base of the coal measures overlying the Millstone Grit.

The seam varies from one inch to thirty inches in thickness. There were vertical joints that cut it into irregular cubes. In a pit at Torbane the section was as follows:

	Feet.	Inches.
Boghead house-coal	2	7
Arenaceous shale	6	0
Shaly sandstone	0	7
Shale and ironstone containing remains of plants and shells	0	10
Cement stone (impure limestone)	0	4
Boghead cannel	1	9
Fireclay full of stigmariæ	0	3

Then came six inches of common coal, and a series of thin seams, one inch or less of black shale, coal, shale, coal, fire clay, etc. The roof above the cement stone contained remains of calamites; the iron nodules, fossil shells of genus *Unio* (E. W. Binney).

THE OIL SHALE.

Good typical shale is of a black or brownish color, fine in the grain and free from grit. It is distinguished by its brown streak, and its resistance to disintegration by weathering. It is tough and sometimes flexible. Under the knife the thin shavings turn up and curl over. Poor shale or "blaes" is friable under the same test; and exposed to the weather soon breaks up into small fragments, and before long crumbles into clay. The richer shales are nearly black but they are found in all gradations of color through brown to gray, as they decrease in quality. They are made up of fine laminæ which become apparent when exhausted of organic matter by distillation. Some shale is "plain," that is, the laminæ are parallel with the stratification of the seam. Other shale is "curly," and the layers, as if by side pressure, are crushed into wave-shaped, curled, irregular masses, with black brightly polished surfaces. There are often plain and curly layers in the one seam, one layer having remained rigid while the other slid and folded itself in the places of reduced pressure.

Although generally called bituminous shale, it is free from bitumen, having practically nothing soluble in ether or petroleum spirit. The carbonaceous matter present is also different from coal. Ordinary coals, by low-temperature distillation, give about 25 to 30 gallons per ton of liquid distillate, which is not a crude oil but a coal-tar, and has a specific gravity of over 1.00; and sulphate of ammonia about 20 lbs. to the ton. The high specific gravity of the tar arises from the large proportion of ringed compounds of the benzene type, etc. In the crude oil of shale the specific gravity is .860 to .880 generally, and it is largely composed of the paraffin or chain series of compounds. There are many shales in the shale measures. The higher ones give a larger yield of crude oil, of higher specific gravity, larger loss in refining and less solid paraffin, and less ammonia. The shales and bastard parrot coals that used to be worked in the higher stratigraphical levels of the coal measures, had still higher specific gravity as of more of the nature of coal, with sp. gr. up to .930 or even .950.

Broxburn seam shale, which may be taken as an example, by ignition in a closed crucible, gave

	Per Cent.
Volatile matter	25.5
Fixed matter	74.5

In the fixed 4.95 was carbon, and 69.55 per cent. ash. The ultimate composition of Broxburn seam shale, dried, was

	Per Cent.
Carbon	19.12
Hydrogen	2.94
Nitrogen	0.54

Mills gives the composition of the ash of good average shale as

Soluble in water (containing SO_3 0.92 per cent.)	8.27
Silica	55.60
Ferric oxide	12.23
Alumina	22.14
Lime	1.55
Magnesia	trace
Sulphur	0.94
Total	100.73

Total sulphur in the shale 1.80 per cent. Total sulphur in the ash 1.31 per cent.

Shales from other parts of the world may be rich in oil, although coarse-grained, gritty, and not curling under the knife.

As an example of shale from the coal measures, the Leeswood seam of Flintshire may be given. Five to six feet were worked.

Upper portion, smooth cannel 25 to 30 inches thick, gave 16 per cent. of crude oil of .925 to .940 sp. gr.

Then curly cannel, 18 inches, giving 30 per cent. crude oil; sp. gr. .875 to .890.

Then shale or bastard cannel 14 to 24 inches, 12 to 15 per cent. crude oil; sp. gr. .900. In some places this shale was replaced by common bituminous coal, and adhering to the cannel above gave a distillate containing the benzene and naphthalene series of compounds as in coal-tar, and spoiled the burning of the lamp oil.

The calciferous sandstone series of the Lothians contains over twenty different seams that have been or are capable of being worked. The ones lying on the higher stratigraphical level may yield as much as 45 gallons crude oil to the ton, the lower ones less, the lowest about 16 gallons. With ammonia it is the reverse,

the upper ones least, 20 pounds or so, the lower ones most, 50 to 70 lbs. to the ton. The gradual change in the nature of the seams as they get deeper may partly arise from the greater age of the deeper ones, combined with the higher temperature to which they have been subjected. There are many seams of igneous rock intruded among the shales, and the heat of these would help to cook the deeper ones to gentle decomposition; for what we have in the shales is the residue of a gentle, age-taking decomposition of organic matter giving results something like destructive distillation. The resulting gases have sometimes escaped; but with an impervious roof they accumulated under pressure and escape when a bore is sunk into the strata. Shale subjected to heat in a covered vessel at about 600° F. or 300° C. distills off almost all the carbon and hydrogen but leaves behind 63 per cent. of the nitrogen (Beilby). Coal at 300° C. in a closed vessel loses a considerable weight but none at all of the nitrogen (Carrick Anderson). So that age, along with the increased but still mild temperature of the greater depths, goes a long way to account for the decreased yield of crude oil but increased yield of ammonia for the deeper shales. The higher shales tend to give a crude oil of higher specific gravity than the lower ones, with less solid paraffin, and this partly arises from age and heat also; but not altogether. Sometimes within a few feet of each other, as in the Leeswood shale before mentioned, there are seams, one of which gives a high, the other a low, gravity of crude oil, from a difference in the original materials deposited—a difference in the proportion of coal-giving materials. A seam of shale, good near the outcrop, often deteriorates as to quantity of oil as it dips deeper under superincumbent strata.

Entomostraca are common in many shales together with fish and plant remains. Animal matter may sometimes add to the proportion of ammonia extracted from shale.

THE CALCIFEROUS SANDSTONE.

This is the lowest division of the carboniferous system. Its distribution is shown on the map, Fig. 53, on page 578. It comes under the Carboniferous Limestone and rests conformably

on the upper Old Red Sandstone. There is a triangle of this formation in the Lothians bounded on the north by the Frith of Forth, on the west by the Bathgate Hills, and on the southeast by the Pentland range of hills. An anticlinal fold or arch coincides with the general line of the Pentlands, and the Lower Old

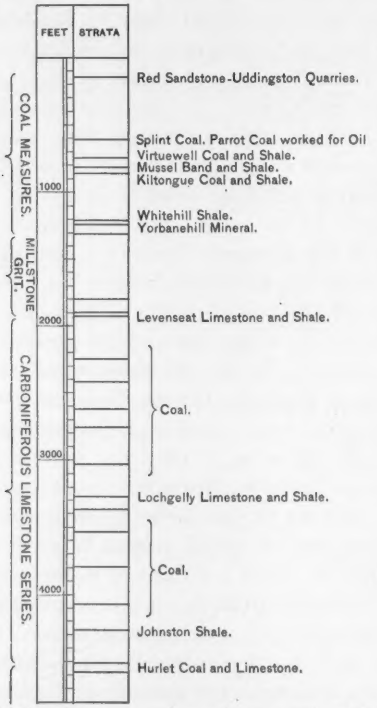


FIG. 60. Generalized columnar section of the shale fields of Mid and West Lothian.

Red Sandstone and Upper Silurian are brought to the surface. Denudation has removed all the carboniferous rocks from the Pentland Hills just as in the calciferous sandstone district all the higher divisions of the carboniferous system have also been

ground off. The country north of the Pentlands would have been reduced to an approximately level plain had it not been diversified by masses of intrusive igneous rock which here and there have produced little hills with the ordinary crag and tail form due to glacial erosion, the crag towards the west and tail towards the east. These relations are illustrated in the section, Fig. 62.

The calciferous sandstone of Scotland consists of two subdivisions: (1) A lower one, the cement stone series or Ballagan beds, varying in thickness from less than a hundred to several thousand feet, made up of alternations of thin clayey limestone or cement stone bands, thin micaceous sandstones, shales and mud stones, but no oil shales. They are evidently lagoon deposits. These crop out towards the east, and a large part of Edinburgh is built upon them. (2) A higher one, the oil shale series, over 3,000 feet thick, which contains the many good shales, and crops out towards the west and forms the good shale country already mentioned, stretching from the Frith of Forth to the southwest end of the Pentlands. There are in it white, red and yellow standstones, blue, gray, green and red marls or clays, blue and black shales, thin coals, fire-clays and estuarine limestones. The sandstones are of great importance for building stone, a considerable proportion of Edinburgh and other towns being built from them. The limestones also are of great economic importance, and besides serving for mortar and for agricultural purposes, have supplied vast quantities of limestone for the iron furnaces of the west of Scotland. The seams of limestone afford great assistance in defining the positions. The richest oil seams of shale lie between the Hurlet limestone which is the upper limit of the oil shale sub-formation, and the Burdiehouse limestone which for long was considered the lower limit; but 800 feet below this position the Pumpherston shales occur. Both Hurlet and Burdiehouse are well known and easily recognized; and certain thin seams of limestone, although of little value economically, are so persistent over the field that they are good guides to the borer in determining his exact position.

One significant feature of the district in connection with the history of the oil shales is the abundant development of igneous

rocks. There are beds of volcanic tuff lying interstratified with the sedimentary strata over considerable areas and in definite positions. There are volcanic necks in seven or eight localities; and sheets of dolorite that cover great areas, one in particular. It has preferred to intrude itself into the position of some good shale or other, not always keeping to the same horizon, however, and at some places itself splitting into several distinct sheets. Over a large area this sheet will only average a few feet, but at certain places it swells out in laccolitic fashion to 80 feet or more. These sheets have generally been intruded when the sediments were comparatively level. Since then the strata and sill together have been wrinkled into great waves, a succession of synclines and anticlines, and these have a general trend north and south. There are four great faults across the shale field with the same general direction—east to west at first and sweeping down to southwest or south. The displacement is often 1,000 feet, sometimes nearly 2,000 feet. The down-throw is to the north except in the most northerly. There are many smaller faults and many branches to these. At one place a dyke of igneous rock 100 feet wide has destroyed the shale for 70 feet on each side of it. There was no gas in the burned shale; but on mining a road through the basalt dyke it was found to be itself charged with inflammable gas under considerable pressure. There was also a spring of brine. The distillation products had been permanent gas. Where, in another place, the sill 5 feet or so thick had taken the place of a shale and destroyed it, there were cavities in the sill partly filled with a yellowish semi-solid hydrocarbon something like vaseline, and the cavities were lined with crystals of calcite, or, rarely, with barite. The hydrocarbon had the composition, carbon 84.35 per cent., hydrogen 12.83 per cent., nitrogen 1.68 per cent., trace of sulphur (R. Tervet). No doubt the hydrocarbon was the product of distillation of the shale and the temperature of the sill had not been high enough to convert all into permanent gas. There was no outlet for the vapors and they had to make room for themselves in the molten trap. Another good seam of shale lying only 8 feet below the sill was not in the least harmed; another proof of comparatively low temperature. The

strata at the time would probably be under water and water-logged, which would help to keep down the temperature, and also shut in the vapors. Often the shale comes close to the igneous rock and is quite good until it practically touches. Sometimes, however, the temperature has been so high and the circumstances such that the shales have been destroyed for a good many fathoms both above and below.

The calciferous sandstone towards the west dips under the coal measures. When it rises again to the surface farther west at the other side of the coal basin, there is no sign of shale. It dips also under the edge coal to the east and when it comes to the surface again beyond the coal field the shales have either disappeared entirely or become so attenuated as to be not worth working. The calciferous sandstone covers a large area in other parts of Scotland; but altogether without oil shale, or with a mere suggestion. So the circumstances suitable for deposits of oil shale seem to have been confined to this limited locality.

The strata of the oil shale field being wrinkled into numerous waves as described, the result of the folding and also of the faulting is to bring again and again the same seams to within working distance of the surface over a considerable area. Instead of having one clean strike north and south the outcrop of the shales forms a wide-stretching network. In searching for shale in a new locality many bores have to be put down, and trial pits, to make certain the shale is sufficiently extensive to be worth the expense of a mine or pit shaft, otherwise faults or intrusive whin may render the whole undertaking fruitless. There is boulder clay over most of the field, sometimes more than 200 feet deep, and this conceals the indications that might be expected on the surface; and often there is little information to be gleaned from stream sections.

Boring to 100 fathoms costs about £300, to 200 fathoms about £800 or £1,000. Sinking a mine costs £15 to £30 a fathom. These all vary much at different times and according to the circumstances.

FIG. 61. General section of the Midlothian. From *The Canonbie Coalfield*. Trans. Roy. Soc. Edin.

FIG. 62. General section of the West Calder shale field, and Carboniferous limestone series to the west (7 miles). After H. H. Caddell, *Geology of the Oil Shale Fields of the Lothians*.

GENERAL SECTION OF THE SHALE DISTRICTS.[1]

The Hurlet limestone and coal is the upper limit of the shale sub-formation.

Strata. 450 ft. at West Calder, 400 ft. at Broxburn, etc., consisting of blaes, ironstone ribs, black-band ironstone, pebbly sandstone, etc.

Raeburn Shale. 3 to 6 ft. thick, giving 40 to 55 gallons of crude oil to the ton and 14 lbs. sulphate of ammonia. Worked in limited areas towards the southwest. In the south Cobbinshaw field there is another shale about 100 ft. above the Raeburn.

Strata. 140 ft. at West Calder, 190 ft. at Broxburn; blaes, fire-clay, sandy blaes, ironstone bands, etc.

Mungle Shale. 2 ft. 35 gallons crude oil, and 30 lbs. sulphate of ammonia. Not much worked.

Strata. 130 to 190 ft.; chiefly blaes with fire-clay and ironstone bands.

Two-feet Coal. 1 to 3 ft. Varies from cannel coal in one district to smithy coal in another. Worked a little at one time at Broxburn along with a thin shale and an ironstone. Immediately above the two-feet coal in some districts are interbedded volcanic tuffs.

Strata. *Houston Marls.* 230 ft. They are green or reddish, massive, amorphous, mudstone-like beds, hard when fresh but crumble down when exposed. In beds of a yard or two in thickness separated by thin bands of a harder and more permanent nature; homogeneous and structureless within the limits of the bed. Unfossiliferous. It has been suggested as accumulation of volcanic dust, but it contains much less silica than the most basic of volcanic rocks. Silica 35 to 40 per cent., ferrous oxide about 3 per cent., ferric oxide 6 per cent., alumina 20 to 22 per cent., lime about 11 per cent., carbonic acid 11 per cent., etc., deposited in water during a long cessation of oil-shale-making conditions.

[1] See general section of Midlothian, page 594, Fig. 61; also comparative columnar section on page 579, Fig. 54.

FIG. 62. General section of the West Calder shale field, and Carboniferous limestone series to the west (7 miles). After H. H. Caddell, *Geology of the Oil Shale Fields of the Lothians.*

Gray Shale of Addiewell. Less than 2 ft. generally. Not much worked. Composed largely of entomostraca, "squeezed together like grains of linseed in oil-cake."

Strata. 60 ft.; blaes, fire-clay, etc.

Houston Coal. 4 to 6 ft. The lowest coal that has been worked to any great extent in Scotland. It lies 2,000 ft. lower than the lowest workable seam of the carboniferous limestone. It is an inferior coal, pyritous, and with blaes interbedded. It had been much worked at the outcrops in very early times, but is not worked now.

Strata. 150 to 250 ft.; thin laminated sandstone, blaes, clay-band ironstone, etc.

Fell's Shale. 3 to 5 ft. thick. The principal shale of the West Calder district. Extensively worked all over the shale district. 26 to 40 gallons crude oil and 20 to 35 lbs. sulphate of ammonia.

Strata. *Broxburn Marl.* 135 to 270 ft. Immediately under the Fell's shale there is generally a limestone 3 to 5 ft. thick, that the borer looks for as proof that the shale is Fell's. Then come greenish, marly or ashy clays with very hard cement stone from 1 inch to a yard in thickness. There are no sandstones.

At Oakbank 12 ft. above the Broxburn seam there is—*The Big Shale,* 4½ ft., 22 gallons, and 13 feet higher still *The Wee Shale,* 1½ ft., 36 gallons. These are generally wanting elsewhere.

Broxburn Shale. This has always been an inferior shale in the West Calder district, 4 to 6 ft.; but it is the principal shale at Broxburn, Oakbank and other localities. At Broxburn there are three seams:

The Broxburn Gray, about 6 ft., 23 gallons, 35 lbs.
The Broxburn Curly, 5½ ft., 26 gallons, 38 lbs.
The Broxburn, 5 to 6 ft., 28 to 35 gallons, 40 lbs.

At Oakbank where these three seams are found along with the two extra ones above, 16 ft. under the Broxburn seam there is another shale of 4 ft., the Wild Shale.

Strata. 400 to 500 ft.; blaes and marl on top and then the *Binny Sandstone,* thick massive beds which have been extensively worked for building stone throughout the district. Blaes and marl below.

Dunnet Shale. 4 to 12 ft. 24 to 33 gallons crude oil and 24 lbs. sulphate of ammonia. The principal shale at Pentland, Duddingstone, and Burntisland, and extensively worked in other districts.

Strata. 400 to 600 ft. Sandstone, blaes, and limeribs. 10 fathoms below the Dunnet seam at Broxburn there is a stratum saturated with petroleum and brine.

Barracks Shale. Sometimes 8 ft. thick and yielding 22 gallons per ton but generally thinner and poorer in oil.

Strata. 40 ft. blaes. Sometimes only 5 ft.

Burdiehouse limestone. Sometimes as much as 64 ft. thick and both quarried and mined. Extensively worked throughout the region. Burned for local use for building and other purposes, and sent off in great quantities to the iron works of the west of Scotland. A fresh-water or estuarine limestone, with numerous fossil fishes, and distinguished by the abundant remains of a small ostracod crustacean *Leperditia Okeni* var. *Scotoburdigalensis.* It often rests upon a characteristic pavement called the "Buckie fake," containing the small gasteropod *Platyostomella Scotoburdigalensis.* Some places this limestone is only 10 ft. thick or less.

Strata. 678 ft. at Broxburn. Blaes with thick sandstones in the center.

Pumpherston Shales.

No. 1, or Jubilee Seam. 8 ft. 18 gallons crude oil, 55 lbs. sulphate of ammonia.

Strata. Blaes, 14 ft.

No. 2, or Maybrick Seam. 5 ft. 16 gallons crude oil, 60 lbs. sulphate of ammonia.

Strata. Blaes and ribs, 13 ft.

No. 3, or Curly Seam. 6 ft. 20 gallons crude oil, 60 lbs. sulphate of ammonia.

Strata. Fakes, blaes, 12 ft.

No. 4, or Plain Seam. 7 ft. 20 gallons crude oil, 60 lbs. sulphate of ammonia.

Strata. Blaes, etc., 12 ft.

No. 5, or Wee Seam. 4 ft. 18 gallons crude oil, 60 lbs. sulphate of ammonia.

BIBLIOGRAPHY.

A full account of the geology of the shale fields may be found in the "Memoirs of the Geological Survey of Britain: The Oil Shales of the Lothians," 1906. Also "The Oil-shale Fields of the Lothians," by H. M. Caddell of Grange, in *Trans. Inst. Min. Eng.*, 1901, or *Trans. Edin. Geol. Soc.*, VIII., p. 116.

The history of the development of the retort is given by Dr. George T. Beilby, F.R.S., in *Jour. of Soc. of Chem. Ind.*, 1897, p. 876. Refining is described in same journal, 1889, p. 100.

ORIGIN OF COBALT-SILVER ORES OF NORTHERN ONTARIO.

REGINALD E. HORE.

The rapidly increasing proved area of silver and cobalt bearing rocks of Northern Ontario has disclosed some new types of deposits, and has afforded additional information regarding the origin of the deposits and of the rocks containing them. It is the purpose of this article to present some results of study in field and laboratory.

IN COLEMAN TOWNSHIP.

The majority of shipping mines are located in the eastern half of this township, and are therefore within a few miles of the town of Cobalt. The producing veins occur in graywacke and feldspathic quartzites and conglomerates of Lower Huronian age, in metamorphosed, fine grained, green igneous rocks of Keewatin age, and in gray diabase-gabbro sills of Post Middle Huronian. In the Huronian sediments and in the diabase, the veins are nearly vertical, while in the Keewatin greenstones the inclination is irregular and the veins less well defined.

In his report[1] on the camp, Dr. W. G. Miller suggested that the fissures now occupied by the cobalt-silver ores in the Lower Huronian were probably formed by the disturbance which accompanied the eruption of the diabase and gabbro, and that the ores may have been deposited from highly heated mineral laden waters associated with the eruption. In a second edition of this report he has suggested that the ores were possibly leached from the Keewatin greenstones, or from the Laurentian granites.

Dr. Van Hise[2] also concludes that the diabase is the source of the ore, and believes that the Keewatin and the conglomerate are the main source of the calcite of the gangue minerals. He

[1] W. G. Miller, Ann. Report, Bureau of Mines, Ontario, Vol. V., 1905.
[2] C. R. Van Hise, *Jour. of Canadian Mining Inst.*, Vol. X., 1907.

suggests that the solutions bearing calcium carbonate were a factor in the precipitation of the metalliferous minerals.

A consideration of later discoveries seems, in large measure, to confirm the truth of these ideas.

RECENT DISCOVERIES.

Cobalt is now known to occur in several areas including the following, which are classed according to the country rock.

In Lower Huronian graywacke—

In Casey township, 15 miles north of Cobalt.

In diabase-gabbro—

In Pense and Ingram townships, 30 miles north of Cobalt.

In Whitson and adjoining townships, 25 miles west of Cobalt.

In James and adjoining townships, 15 miles north of Whitson.

In the vicinities of Portage Bay, of Trout Lake, and west of Anima Nipissing Lake.

In Keewatin—

South of Lorrain township, 16 miles southeast of Cobalt.

Of these localities, Casey Twp., Whitson Twp., James Twp., and the area south of Lorrain show native silver in addition to cobalt minerals.

The following description applies to the rocks found over the large area including these deposits.

DIABASE-GABBRO.

The intimate connection of this rock with the ore deposits has been recognized by the prospectors for some time, and it is becoming more apparent as exploration advances.

It occurs in most cases in the form of large sills, a few hundred feet in thickness, lying nearly horizontal and parallel to the bedding of the Huronian sediments. The greater part of the sills is dark gray in color and holocrystalline. The chief minerals are augite and plagioclase (labradorite to bytownite), while ilmenite is generally present and quartz is common. At the edge of the sheets the rock is very fine grained, and, though markedly ophitic in texture, is not readily distinguished from intruded slates. A few feet from the edge the grain becomes quite noticeable, and

at some distance very coarse textures were often found. These coarser portions, often pink in color, show a considerable percentage of quartz and orthoclase, often in micrographic intergrowth. Barlow's descriptions[1] of numerous occurrences of this rock in the area covered by the Nipissing and Temiscaming map sheets, indicates that they are all derivatives of the same magma.

In petrographical character and in their relations to the Huronian sediments they are remarkably similar to diabase sills of the Lake Superior district, which are regarded as of Keweenawan (being the plutonic equivalent of the surface flows of the Copper district) or of Post-Keweenawan age.[2]

VEINS IN DIABASE-GABBRO.

Veins are not common in the diabase, and of these calcite are less numerous than quartz. Although quartz veins carrying cobalt ores are known, the silver is confined to veins having calcite gangue. In the rich deposits in Coleman Twp., there is little gangue, the veins being seldom more than a few inches in width and often composed entirely of ore. In some cases native silver is the most abundant filling, forming thin films along the joint planes.

The quartz veins frequently carry small amounts of pyrite and chalcopyrite. West of Wakemika Lake there are several quartz veins, one to two feet in width, which carry argentiferous galena along with pyrite, chalcopyrite, and a later filling of pale pink calcite.

Some barite veins in James Twp., are said to be argentiferous.

INTRUSIVES IN DIABASE-GABBRO.

There occur in the large sills small intrusions, some more, others less siliceous than the main mass.

In Coleman Twp., there are fine-grained dark-colored dikes of olivine diabase, while near Temagami there are small dikes of diabase porphyry.

More common and more interesting from an economic stand-

[1] A. E. Barlow, Geol. Sur. Canada, Ann. Rep., Vol. V., Part I., 1897.

[2] A. C. Lane, Geol. Sur. Michigan, Vol. VI., Part I., pp. 219 et seq. A. E. Lawson, Geol. Sur. Minnesota, Bull. No. 8, p. 47, 1893.

point are the light-colored aplite veins. The width of most of these is to be measured in inches, and they are generally but a few hundred feet in length. They are fine grained and usually of pink color, being composed largely of quartz, orthoclase and the more sodic plagioclases. The proportions of quartz and feldspars vary considerably in the same vein. There is considerable chlorite in darker colored portions, and calcite fills in the interstices. Small crystals of apatite and titanite are inconspicuous but characteristic constituents.

Most of these aplite veins carry some pyrite, chalcopyrite, or galena, and some carry cobalt and silver ores. It was noted in some cases in James Twp., that the sulphides occur along fractures in the narrow veins and from this it is inferred that the metalliferous solutions followed the deposition of the aplite. It is also noted that the feldspars remain rather fresh, and that they were therefore inactive in precipitating the ore. The dark-colored silicate present however, is chlorite, and is probably the result of the action of these solutions on pyroxene or amphibole, yielding at the same time lime for the formation of calcite when carbon dioxide was available.

DISSEMINATED ORE IN DIABASE-GABBRO.

In the diabase which extends westwards from Anima Nipissing Lake to Lady Evelyn Lake, there are several showings of cobalt minerals, both in calcite veins and as disseminated crystals in the diabase. There is generally little or no surface indication of the latter; but on breaking the rock traces of cobalt bloom are found.

One such deposit, west of Diabase Lake, is associated with an aplite vein. This vein is about one foot in width and is exposed for about 150 feet, it carries some pyrite and chalcopyrite; but little cobalt. Parallel to the vein and for a few feet from its walls, the diabase contains disseminated crystals of smaltite which are more abundant along the joint planes. The chief unaltered constituent of the ore-bearing rock is feldspar. The crystals of smaltite, accompanied by some small titanite crystals, are embedded in calcite and chlorite, and more rarely in the feldspars. In the latter case it is to be noted that there are many cracks, partly

filled with calcite, which have evidently served as channels for the introduction of the smaltite.

Another cobaltiferous specimen, also chloritic, from the same region shows some kernels of augite still undecomposed, and a high percentage of ilmenite.

Origin of Disseminated Ore.—The detection by the naked eye of scattered smaltite crystals in the diabase, suggests the possibility of its being an original constituent in the rock. On the other hand, the association with aplite suggests that the ore had its origin in the solutions that accompanied these intrusions.

The microscopic examination outlined above shows that the smaltite is of secondary origin. It was at first thought that possibly the augite was cobaltiferous; but, on examination, a specimen of the rock containing kernels of this mineral was found to contain no trace of cobalt.

Accordingly the following conclusions may be drawn: (1) That the smaltite was introduced by solutions associated with the aplite intrusion; (2) that such solutions came after the crystallization of the aplite; (3) that the intrusion disturbed the diabase to such an extent that a zone was formed in the latter which was more permeable to the solutions that was the aplite itself; (4) that these solutions had little action on the feldspars; but found other silicates quite active chemically. Further conclusions may be deduced from a consderation of the origin of the aplite.

Origin of the Aplite.—The most apparent difference between the aplite and the diabase is the color. This is due to a higher percentage of quartz and alkali-feldspars, and a corresponding lower percentage of dark-colored silicates, so that the aplite is generally light pink in color while the diabase is dark gray.

It has already been mentioned that portions of the diabase sill at some distance from their edge are coarse in texture and sometimes pink in color. Here again the difference in color is due to a greater development of quartz and less augite. The distance from the edge of the sheet, and the coarse texture show that these more siliceous portions have crystallized later than the main mass. This shows that differentiation has taken place in

such a way that the melt has become more siliceous, possibly approaching a eutectic mixture. These pink coarse-textured portions have a mineralogical composition intermediate between that of the gray portion and that of the more siliceous aplite.

From the composition and the field relations it is thought therefore that the aplite is a later secretion from the further differentiated diabase magma.

The relation of the aplite to the diabase is very similar to that of "contemporaneous veins" in rocks described by Waller and Teall.[1] It is thought justifiable therefore to apply this term to the aplite occurrences.

Origin of the Metalliferous Solutions.—It has already been shown that the ores were deposited from solutions which followed the aplite intrusions.

The origin of these solutions cannot be proven; but the association with aplite suggests a genetic connection. It seems that as the diabase magma cooled and crystallized the melt was approaching a eutectic of predominating salic composition. If water and metallic sulphides and arsenides were being concentrated, this was probably by the formation of a solution whose constituents were not soluble in all proportions in the silicate solution. The former solution was not miscible with the latter, and remained liquid or gaseous after temperatures had been reached at which the latter had solidified. When fractures in the diabase provided means of escape, part of the metalliferous solution doubtless accompanied the aplite solution, and, as has been shown above, part escaped subsequent to the aplite deposition.

That such a deposit is due to extreme differentiation in the igneous magma, is in harmony with the expressed views of J. E. Spurr[2] regarding the origin of most metalliferous deposits.

While no silver was found in the rock sections examined, the occurrence of native silver with cobalt minerals in aplite in James and adjoining townships, indicates a similar origin for the silver.

[1] J. J. H. Teall, "British Petrography," London, 1888, p. 275.

[2] J. E. Spurr, "A Theory of Ore Deposition," Econ. Geol., Vol. 2, pp. 781–795.

While it has been shown that in the veins at Cobalt silver solidified later than cobalt minerals,[1] the occurrence in aplite indicates that there was no great time interval.

Influence of Keewatin and Huronian Rocks.—Having concluded that the cobalt-silver-bearing solutions are the result of differentiation in the diabase magma, we have now to consider the role of the intruded rocks in precipitating the ore.

Van Hise has stated "that the calcite gangue could not be derived from the diabase since it contains no carbonates, or so small a quantity that it is negligible. But one of the most characteristic features of the Keewatin rocks is the presence of carbonates, among which calcite is the most abundant. Also the conglomerate, being composed of débris from the Keewatin, contains much carbonate." He infers "that the Keewatin and the conglomerate are the main source of the calcite of the gangue minerals," and suggests "that the precipitation of the ores was produced by the mingling of solutions, some of which came from the diabase bearing the ores, and others of which came from the conglomerate and Keewatin, bringing precipitating agents"; but "the mere cooling of the solution may have been a factor in the process."

In the discussion following Van Hise's paper,[2] Miller pointed out concerning the cobalt-silver veins west of Peterson Lake, that "in practically all cases the silver values disappear in passing from the conglomerate to Keewatin but the smaltite and niccolite continue below the contact." He suggests "that during a period of secondary disturbance the silver filled in the cracks through the smaltite or older minerals." But the older Keewatin "seems to have escaped the effects of this slight disturbance, hence there were no cracks in it, and the solutions could not get through the Keewatin."

THE KEEWATIN.

A clearer idea of the part played by the intruded rocks is to be obtained by a study of the character of the Keewatin and Huronian formations over the wide area in which cobaltiferous diabase is now known to occur.

[1] Wm. Campbell and C. W. Knight, ECON. GEOL.

[2] *Jour. Canadian Mining Inst.*, Vol. X., 1907.

In Coleman township this formation is represented by igneous rocks only. Perhaps the most abundant type is a fine-grained green rock in which there is considerable chlorite and calcite, and still undecomposed remnants of augite. There are also intrusions of coarser-textured rocks which appear to be altered gabbros and diabases.

In Casey Twp. there is an outcrop of a dark green, fine-grained rock which appears to be an altered basalt, and in Tudhope township a coarse-textured greenstone intruded by Laurentian granite was observed.

In other areas sedimentary rocks are associated with those of igneous character. At Larder Lake there are auriferous cherty carbonates, while at Temagami there are carbonates and cherty iron ores.

A study of Miller's map[1] shows that none of the ore-producing veins are located more than a few hundred feet away from igneous Keewatin rocks. Equally significant is the fact that in areas in which the latter are not found, the cobalt-silver deposits are less extensive, and many cobaltiferous veins contain no native silver.

As Van Hise has indicated, these rocks contain a considerable percentage of calcite which furnished the gangue. It is also to be noted that there are present many relatively unstable minerals, *e. g.*, pyroxene, hornblende, and biotite, which are readily acted on by percolating waters. These minerals are active chemical agents, and doubtless by their reactions with ore-bearing solutions aided in the precipitation of the ores. From the field study it seems beyond doubt that such has been the case.

THE LOWER HURONIAN.

This formation is represented by graywacke slate, feldspathic quartzite or arkose, and graywacke conglomerate, in ascending order. The strata have, as a general rule, been but slightly disturbed from their original positions; but in some places are inclined as much as 45°. Their character has apparently been

[1] W. G. Miller and C. W. Knight, Map of Cobalt Area, Bureau of Mines, Ont., 1907.

but little changed by igneous or dynamical agencies of metamorphism, except at the immediate border of the diabase where some hardening has taken place by a recrystallization of quartz.

In some areas, notably Temagami, Cobalt, Casey Twp., Wendigo Lake and Larder Lake, the graywacke slate and conglomerate predominate over the arkose. In others, notably the region from James Twp., to Lady Evelyn Lake, there is a greater thickness of the arkose.

From numerous petrographical descriptions by A. E. Barlow and G. H. Williams, in Barlow's report, supplemented by the writer's examination of the rocks in the more immediate vicinity of the ore deposits, the arkose is known to be made up almost entirely of quartz, orthoclase, plagioclase, sericite and chlorite. Quartz and orthoclase predominate, and of the plagioclases the more sodic varieties are most abundant. The grains are often subangular and much fractured, their size is that of a medium grained granite.

The graywacke, so far as can be determined, is made up of similar minerals more finely pulverized. The percentage of chlorite is higher; but there is an absence of fragments of primary ferro-magnesian minerals, and the rock is therefore not a typical graywacke.

The pebbles in the conglomerate represent numerous types of Keewatin and Laurentian igneous rocks, and occasional cherty sediments. Light colored granites, probably Laurentian, are the most abundant of the pebbles.

From the character and composition of the mineral fragments which constitute them, there can be little doubt that the arkoses were formed from the granitoid Laurentian rocks, and not from the metamorphosed greenstones of the Keewatin. It follows also that much of the graywacke is the finer material from the same source; but what percentage of the graywacke is made up of detritus of the Keewatin cannot be determined.

Dr. A. P. Coleman[1] has shown that some pebbles in the conglomerate at Cobalt have suffered from glacial action. From the examination of numerous basal unconformities however,

[1] A. P. Coleman, *Jour. Geol.*

one must conclude that they are not due to morainal deposition following the grinding action of glaciers. A photograph of one of these unconformities is shown in Miller's report.

The gradual transition from slate and arkose to the upper conglomerate bed shows that the latter is not of the common glacial type. The boulders of the upper bed, however, may be the erratic deposits of drifting ice; though glacial material is apparently a minor factor if present at all.

Bell[1] describes the conglomerate as a volcanic breccia. Miller suggests that "some of the delicately banded graywacke slate may represent volcanic dust or fine grained pyroclastic material," but that the lower conglomerate is not pyroclastic and is made up of fragments of the adjacent older series.

The examination of thin sections of graywacke shows an absence of glass or mineral fragments so characteristic of volcanic dust. The chemical analysis shows it to be of a composition similar to an ordinary palaeozoic shale.

	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	FeO	CaO	MgO	Na_2O
A	60.15	16.45	4.04	.76	2.09	1.41	2.32	1.01
B	62.74	16.94	5.07		1.59	1.39	3.05	6.07

	K_2O	H_2O	CO_2	SO_3	C	BaO	P_2O_5
A	3.60	4.71	1.46	.58	88.	.04	.15
B		3.56					

(A) is a composite analysis of 51 palaeozoic shales, by H. N. Stokes of the U. S. G. S.

(B) is the analysis of graywacke slate from the Little Silver Mine, made by A. G. Burrows of the Ontario Bureau of Mines.

The writer concludes therefore, (1) that there was no volcanic activity contemporaneous with the Lower Huronian, (2) that these rocks were formed entirely of the detritus of the Laurentian and Keewatin formations, (3) that the Arkoses, at least, are primarily of Laurentian origin

INFLUENCE OF LOWER HURONIAN ROCKS.

Attention has already been drawn to the fact that the feldspars were but slightly, if at all, altered by the ore-bearing

[1] Dr. Robert Bell, "The Cobalt Mining District," *Jour. Can. Mining Institute*, 1907, p. 64.

solutions. Chlorite, sericite and quartz are well known to be stable minerals, and it therefore follows that the arkoses cannot have been active agents in depositing the ores.

The graywacke is made up of similar minerals with a larger percentage of secondary products. Calcite is sometimes present in very small amounts, and it is noteworthy that these rocks show a marked deficiency in lime, as compared with the Keewatin. It is thought therefore that while the Keewatin greenstones have probably, by virtue of their mineralogical composition, played an important role in the deposition of the ores, the graywacke, being composed of more stable minerals and low in calcite, played the same role in a minor way, if at all. The pebbles in the conglomerate contain numerous primary ferro-magnesian minerals which would be readily decomposed, and so the coarse conglomerate may have been more active than the graywacke slate.

Owing to their regular vertical jointing these sediments have afforded the most suitable place for the deposition of the ore, and so it happens that many of the most valuable veins have been found in them.

DEPTH OF COBALT-SILVER VEINS.

Miller has pointed out that marked changes in silver values take place in passing from conglomerate to Keewatin rocks. Considerable silver is being mined from the latter; but it has in most cases been found that the veins are not so regular as in the overlying shell of conglomerate. The lower limit of the deposits has not yet been determined. There are no borings of more than a few hundred feet, and it is consequently not known whether there is another diabase sill at a lower horizon. Solutions from a lower sill would find in the intruded Keewatin an agent which assists in deposition; but there can be no repetition of the Huronian sediments.

CONCLUSION.

It has been shown that cobalt ores have been deposited from solutions which followed the formation of veins of aplite in the diabase. Owing to the fact that in all the silver deposits in the

district the silver minerals are intimately associated with cobalt minerals, the silver is believed to have the same origin.

It is suggested that the metallic sulphides and arsenides have been concentrated from the diabase magma by extreme differentiation.

The Keewatin igneous rocks have assisted in the ore deposition on account of their content of calcite and unstable minerals.

The Huronian sediments are composed for the most part of stable minerals with little calcite, and their chief function has been that of a recipient for the ores.

If these conclusions are correct, we may expect to find similar ore deposits where the diabase sills are associated with Keewatin igneous rocks, and especially valuable deposits where Huronian sediments are also present. The region from Lake Temiscaming to Lake Huron doubtless includes many such occurrences.

A GENETIC CLASSIFICATION OF MINERALS.[1]

WILLIAM H. EMMONS.

That certain minerals are formed under certain definite physical conditions is a principle which has long been recognized. It was elucidated in the brilliant work of Gustav Bischof and to a certain extent it pervades the geological literature of both the present and past generations. It has been emphasized by Dr. C. R. Van Hise in his treatment of geological problems and especially in his studies of regional metamorphism.[2]

The first comprehensive treatment of the broadest application of the principle to ore deposits is the paper by Mr. Waldemar Lindgren, which appeared in a recent number of ECONOMIC GEOLOGY,[3] and which embodies some of the results of his previous studies, among them his review of metasomatic processes[4] in fissure veins.

It is the purpose of the present paper to indicate briefly the principal conditions under which the most important minerals are formed. The data supplied by the papers mentioned above have been freely incorporated, and much information has been obtained from the published works of Barlow, Boutwell, Clark, S. F. Emmons, Hammerschmidt, Hayes, Hintze, Iddings, Irving, Kemp, Leith, Moffit, Penrose, Ransome, Rosenbusch, Spencer, Spurr, Weed, Wright, and a number of others who have made careful studies of the mineral groups, which constitute certain deposits of which the genesis is well understood through a knowledge of the geological conditions which held when deposits were formed. Studies by Chamberlin, Bain, Rogers and Grant have given us a very satisfactory knowledge of the mineralogy of the zinc-lead deposits of the Mississippi Valley, and these are

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] Treatise on Metamorphism.

[3] Vol. 2, p. 448.

[4] "Genesis of Ore Deposits," p. 498.

of peculiar interest since their associations of minerals are different from most of those of the Cordillera region, the ore deposits of which are in the main closely associated with igneous rocks.

The plan of the present classification of minerals is closely similar to that employed by Lindgren,[1] but a column is introduced for ore deposits which occur in areas which are without outcrops of igneous rocks and the column for minerals of the middle and upper vein zone is reserved for the minerals of such deposits which are near outcrops of igneous rocks, or which are inclosed in igneous rocks. Another column is added for minerals which are formed by dynamo-regional metamorphism.

The reliability of the data given in this paper is greatly increased by the circumstance that the tables have been inspected by a number of geologists, each of whom has made extended studies in one or more of the groups of minerals. They have been critically reviewed in part or altogether by Messrs. Lindgren, Bastin, Calkins, Graton, Hess, Johannsen, Leith, McCaskey, Siebenthal and Spencer. Upon the subject of the genesis of some minerals it therefore approaches the record of a symposium.

Column 1 is intended to include the rock-making minerals or the minerals which may be formed by the cooling of magmas under various conditions.

Column 2 is intended to include the more common minerals, which are formed in pegmatite veins. A large number of rare earth minerals not associated with metalliferous ores are not mentioned, since that would make the list too bulky to be most useful. It is recognized that many rocks may properly be considered gradational between igneous rocks and pegmatites, but the tendency here has been to place the minerals which compose them in column 2 (the pegmatite column).

Column 3 contains the minerals of contact metamorphic origin —minerals which are formed in calcareous or other sedimentary rocks by recrystallization of elements contained in those rocks, and by the addition of new elements from solutions which are given off by cooling igneous rocks near-by. Some of these min-

[1] *Loc. cit.*, p. 125.

erals, such as epidote and mica, may be formed in an igneous rock through contact metamorphism where another igneous rock intrudes it, while other minerals, such as garnet, are, in contact metamorphic deposits, probably confined to calcareous sedimentary rocks or to fragments and masses of such rocks which were included in the igneous rocks. There is no attempt here to separate the two groups of contact metamorphic minerals for the data are at present insufficient for such a division.

Column 4 of the table includes minerals which are formed in the deep vein zone. The importance of this group of deposits and its recognition as a type illustrating the results of deposition under conditions of greater pressures than those which obtained when most of the deposits of the Rocky Mountains were formed, was first recognized in the studies of Lindgren[1] and Graton.[2] The associations of minerals formed in these veins resemble more closely the associations formed by contact metamorphic processes than do the minerals of the Tertiary veins of the Rocky Mountains which were deposited at moderate depth. The heading of the column refers to the depth of the vein zone, but it is fully recognized that the principal condition which differentiates this group of minerals from other groups is one of pressure rather than depth. The pressure depends upon depth in the main, but if the solutions which deposit these minerals are for any reason under greater pressure than the simple hydrostatic pressure which would hold at the depth at which they are deposited, and if the openings which the solutions enter are very small and are not connected freely with the surface then it is possible for pressures to be maintained during crystallization, which are in excess of the pressures which would obtain in large openings at the same depth, if the latter were connected directly with the surface, and where the pressure at the locus of deposition is simply that which is due to the weight of the column of water above. In the Phillipsburg quadrangle, Montana, such replacement veins contain minerals which are normally formed in the

[1] *Loc. cit., et al.*

[2] "Reconnaissance of some Gold Deposits of the Southern Appalachians," *Bull. U. S. Geol. Surv.*, No. 293.

deeper veins and under contact metamorphic conditions, but which are seldom or never formed in veins deposited at moderate depth as simple fissure fillings and probably communicating directly with the surface. These veins, containing specularite and pyrrhotite, were probably formed at about the same depth as some simple fissure fillings near-by which did not contain these minerals, but there is reason to believe that the latter group was formed in open spaces which connected freely with the surface and possibly under simple hydrostatic pressure, while the specularite-bearing veins were formed by replacement of limestone in narrow and perhaps complexly branching fissures, through which the connection to the surface was by way of devious paths along which there was too much friction for conditions of simple hydrostatic pressure to be maintained. It was thus possible for solutions, which are believed to have been somewhat similar to contact metamorphic solutions, to deposit their load under great pressure along narrow openings which were not connected directly with the surface. Thus the deposition probably took place only at moderate depth, but because of the great pressures, the minerals of the deep vein zone were formed. Thus column 4 is intended to include not only the deposits of the deep vein zone but also the deposits formed at moderate depths but under such conditions of pressure as those which normally obtain in the deep vein zone.

That there is a basis for a division of minerals formed in deposits associated with igneous rocks and those formed in deposits which are remote from igneous rocks was suggested by Bain,[1] who pointed out the fact that in their mineralogy the vein deposits of southern Illinois and western Kentucky which are associated with igneous rocks have a closer resemblance to the deposits of the Rocky Mountains than to the other metalliferous deposits of the Mississippi Valley. Fluorite and stibnite, which are present in the Kentucky deposits and in many of the Cordilleran deposits, have never been reported from the zinc deposits of Missouri and Wisconsin, which are far removed from outcrops of igneous rocks.

[1] Economic Geology, Vol. II., No. 2.

Very few students of ore deposits will deny the probability that meteoric waters have, under favorable conditions, deposited large bodies of workable ore. On the other hand, the presence of igneous rocks is known to be the most uniform condition for deposition of the ores of the Cordilleran types. The prevailing tendency of many investigators is to regard many of these deposits as having been formed by deposition from solutions which were set free from cooling magmas as they solidified to form igneous rocks, but it is not within the scope of this paper to discuss the efficiency of such waters or to compare their work with that of meteoric waters which, having come in contact with hot rocks, may, through an increase of temperature become more active reagents for dissolving the minerals in the rocks through which they pass.

Column 5, therefore, is intended to include minerals which are formed under both sets of conditions and at moderate and shallow depths whatever the source of the water which deposited them, but only those minerals which have been found in deposits which are in or near igneous rocks and which are presumably related to them genetically. Probably all of the minerals of column 5 are primary, though many of them are secondary also.

Column 6 is intended to include only those deposits which are found in sedimentary rocks far from intruding igneous rocks, and which are regarded by those who are most familiar with them as having no direct genetic connection with igneous rocks. These minerals were deposited presumably by cold solutions or by solutions which were not more highly heated than are the rocks in the lower limits of ground water under normal conditions free from intrusion of igneous rocks and free from intense movement which produces heat. Minerals which may be secondary in such deposits are included in the list.

Column 7 includes the minerals which are formed in the zones of sulphide and oxide enrichment. All of them have been identified in veins of which the primary ore would be designated under the caption of column 5. Doubtless many other minerals will be added to this list as the knowledge of secondary enrichment increases. Like the minerals of column 6 these minerals

have presumably been deposited by cold solutions of meteoric water. There is, however, a much greater variety of minerals in column 7 than there is in column 6, perhaps because the solutions which deposited them are much more highly concentrated, since they have dissolved the salts which they carry from a relatively highly concentrated deposit, that is, from the primary ore of a vein such as would be designated by the caption of column 5. There is a greater variety also because the descending waters causing secondary enrichment have dissolved an ore which is already chemically complex. Some of the minerals of column 7 are simply the oxidation products of the minerals of column 5, and some of them are secondary sulphides.

It is not possible to make a definite statement comparing the chemical nature of the solutions which deposited the minerals of column 5 with those which deposited the minerals of columns 6 and 7. The distinctions are simply those gained by observation and experience; although they depend upon physical and chemical laws, it is not within the scope of this paper to examine those laws in detail. Several sulphates are found in this column, among them barite, celestite and alunite, but when one considers the great insolubility of some of these sulphates and the fact that all of them are relatively rare in most of the veins of this group and that in a large number of them they do not occur at all, the conviction grows that the solutions which formed the deposits of the caption of column 5 are very rarely strong sulphate solutions.

It is known that many of the veins which are included under this caption were deposited by solutions rich in carbonates, sulphides and silica. Such solutions usually form very weak acids and their salts are therefore likely to be alkaline. Indeed, it is regarded as highly probable that most of the minerals of column 5 may be deposited by alkaline solutions. From structural relationships it is also known that many of the veins of column 5 were deposited by ascending solutions. Still, the direction of the circulation can be proved only in favorable cases and it would be unsafe to make a general statement; but it is probable that a

great many of the deposits of this group are such as may be formed by precipitation from ascending alkaline waters.

On the other hand, the secondary minerals of column 7 are known to form where there is a large excess of cold sulphuric acid, and most of them are presumably precipitated from sulphate solutions. This acid and its salts are the chief chemical agents of secondary sulphide enrichment. The chemical nature of the solutions which form the deposits of the caption of column 6 is not known, but since they deposit great quantities of the sulphides, they are certainly sulphur-bearing; and since they are supposed to be ground waters which have dissolved their metalliferous content from the country rock, they were presumably highly oxidized. A large number of the deposits of this group were probably formed by sulphate solutions just as are the deposits of sulphide enrichment.

Column 8 includes the minerals which have been formed by processes of dynamo-regional metamorphism. It is a very difficult matter to draw the line sharply between conditions of regional metamorphism in which the predominating processes are due to pressure, to movement, to the heat which they produce, and to the activity of ground water; and conditions of contact metamorphism where solutions given off by igneous rocks are active in adding new elements and in forming new mineral combinations, some or all of the elements of which may be derived from the contact metamorphosing solutions. Possibly the list of column 8 is the most unsatisfactory of all, because it is not always possible to state definitely what the material was before it was subjected to regional metamorphism. It is evident that any rock or ore formed at first under the conditions indicated by the headings of columns 1 to 7 may later have been subjected to dynamo-regional metamorphism. As a result of recrystallization under such conditions groups of minerals are produced in the resulting metamorphic rocks, which may closely resemble the associations of minerals which result under conditions of contact metamorphism. It is the opinion of Mr. A. C. Spencer that the deposits of Franklin Furnace, N. J., which contain very un-

Mineral.	1 Igneous Rocks.	2 Pegmatite Veins.	3 Contact Metamorphic Deposits.	4 Deposits of Deep Vein Zone.	5 Deposits of Moderate and Shallow Depth. Igneous Rocks Nearby.	6 Deposits of Moderate and Shallow Depth. *No* Igneous Rocks Nearby.	7 Secondary Minerals in Zones of Oxide and Sulphide Enrichment.	8 Products of Dynamo-regional Metamorphism.	Remarks and Authorities.
Acmite	+	+						+?	Van Hise.
Actinolite	+?		+					+	Not definitely known as primary in igneous rocks. Rosenbusch.
Adularia				?	+		+		7 Lake S. Iron ores.
Aegerite	+								Iddings.
Alum						+	+		
Alunite					+	?	+		Ransome; 4 Lindgren.
Albite	+	+	+	+				+	
Allanite	+	+	+					+	
Amalgam							+		
Amphiboles	+	+	+	+				+	Lindgren.
Analcite	+						+		1 Cross, also secondary.
Andalusite	+?	+	+					+	1 Michel Levy, 2 Lindgren.
Andradite	+?	?	+	+?				+	3 Lindgren, Kemp.
Anglesite						+	+		Hammerschmidt.
Anhydrite				+				+	4 Lindgren, 8 Van Hise.
Ankerite			+	+	+	+	+	+	Van Hise; 3, 5 Lindgren.
Anorthite	+	+	+					+	2, 3 Lindgren.
Anthophyllite								+	Van Hise.
Antimony							+		
Apatite	+	+	+	+	+	+	+	+	1–5 Lindgren, 6–7 Leith.
Aquamarine		+							
Apophyllite							+		Surface alteration.
Arfvedsonite	+								Iddings.
Argentite					+		+		Spurr,
Aragonite						+?	+		Dana.
Arsenic							+		Treadwell mine, Spencer.
Arsenopyrite		+	+	+	+				Lindgren.
Atacamite						?	+		Kemp.
Augite	+	+?	+					+	Van Hise.
Aurichalcite						+	+		6 Rogers.
Azurite						+	+		
Barite					+	+	+?		
Bastite								?	Surface conditions.
Bauxite					+	+	+		5 not in veins proper; 5, 6 Hayes.
Beryl		+	+						
Bismuth		+					+		2 Hess, 7 Lindgren.
Bismuthinite		+?	+	+?	+				3 West Cananea, W. H. Emmons.
Biotite	+	+	+	+				+	4 Alaska, Spencer.
Bornite		+	+	+	+	+	+		6 Lindgren.
Bort	+		?						
Bromyrite							+		
Brookite				+?	+?				Also surface alteration.
Brucite									Weathering at surface.
Calamine						+	+		6 Van Hise, 7 Ulrich.
Calaverite				+	+				4, 5 Lindgren.

Mineral.	1 Igneous Rocks.	2 Pegmatite Veins.	3 Contact Metamorphic Deposits.	4 Deposits of Deep Vein Zone.	5 Deposits of Moderate and Shallow Depth, Igneous Rocks Nearby.	6 Deposits of Moderate and Shallow Depth, No Igneous Rocks Nearby.	7 Secondary Minerals in Zones of Oxide and Sulphide Enrichment.	8 Products of Dynamo-regional Metamorphism.	Remarks and Authorities.
Calcite	+?	+?	+	+	+	+	+	+	1 probably secondary, 2 Johannsen.
Caledonite						+?	+		
Calomel							+		
Cancrinite	+								Van Hise.
Cassiterite	+	+	+	+					Lindgren.
Celestite					+	+	+		6 in beds with rock salt.
Cerussite						+	+		6 Rogers, 7 L. D. Ricketts.
Cerargyrite					+		+		Spurr.
Chalcanthite						+	+		
Chalcedony					+	+	+		Lindgren.
Chalcocite				+	?	+	+		4 Graton, 6 Lindgren.
Chalcopyrite	+	+	+	+	+	+	+	+	Lindgren.
Chert					+?	+	+		
Chlorite			+?	+?	+		+	+	Also weathering product.
Chromite	+	+?	+					+	
Chrysocolla						+	+		6 Rogers.
Cinnabar				+	+		?		4, 5 Lindgren.
Cobaltite					+				
Copper					+?	+?	+		
Corundum	+	+	+					+	
Cordierite	+		+					+	Van Hise.
Covellite						+	+		6 Rogers.
Cryolite	?	?	?	+					
Cuprite						+	+		6 Rogers.
Cyanite		+	+					+	3, 8 Van Hise.
Diallage	+							?	
Diamond	+		?						1 Lindgren.
Diopside	+	+	+	+				+?	
Dolomite			+?	+	+	+	+	+	Lindgren.
Eleolite	+								Iddings.
Emerald		+	+						Dana.
Emery	+	+	+					+	
Enargite					+		+?		
Epidote	+?		+	+				+	Also by weathering.
Fayalite	+								
Fluorite	+	+	+	+	+	+?		+?	
Forsterite	+		+						Johannsen.
Franklinite			+					+	3 and 8 Spencer, 4 Lindgren.
Gahnite			+	+				+	3 and 8 Spencer.
Galena		+?	+	+	+	+	+	?	2? Spencer.
Garnet	+	+	+	+				+	
Gay-Lussite									Evaporation.
Gibbsite									Weathering product.
Glauconite									Formed with sediments.
Glaucophane			+?					+	
Gold (native)	+	+	+	+	+	+	+	+?	
Goslarite						+	+		6 Rogers, 7 Ulrich.

Mineral.	Igneous Rocks. 1	Pegmatite Veins. 2	Contact Metamorphic Deposits. 3	Deposits of Deep Vein Zone. 4	Deposits of Moderate and Shallow Depth. Igneous Rocks Nearby. 5	Deposits of Moderate and Shallow Depth. No Igneous Rocks Nearby. 6	Secondary Minerals in Zones of Oxide and Sulphide Enrichments. 7	Products of Dynamo-regional Metamorphism. 8	Remarks and Authorities.
Greenockite					?	+	+		6 Rogers, 7 Hess.
Graphite	+	+	+	+				+	4 N. J. Spencer.
Gypsum					?	+	+		Evaporotion also.
Halite									Evaporation.
Haüynite	+								
Hematite	+	+	+	+		+?	+?	+	6 and 7 see turgite.
Hornblende	+	+	+	+				+	
Humite group			+						
Hydrozincite						+	+		7 Lindgren.
Ilmenite	+	+	+	+				+?	8 Rosenbusch.
Ilvaite	+?		+						Lindgren.
Iron (native)	+								1 basalt from Greenland.
Jadeite	+?	+?	+?					+?	
Kalgoorlite				+	+?				4 Lindgren.
Kaolin					?	+	+		Hot water near surface, also weathering product.
Lead (native)							+		
Leadhillite						+	+		6 Rogers.
Lepidolite	+?	+		+				+	4 Hess, Texas; 8 Rosenbusch.
Leucite	+								Iddings.
Limonite						+	+		
Magnesite					+	+?	+		7 Hess.
Magnetite	+	+	+	+			+?	+	Lindgren.
Malachite						+	+		
Manganite						+	+		
Marcasite					+?	+	+		Lindgren.
Melaconite						?	+		7 Kemp.
Melilite	+								Rosenbusch.
Mercury							+		
Microcline	+	+	+					+	3 Calkins, 8 Van Hise.
Millerite					+?	+?	+		5 Lindgren, 6 St. Louis Co. Mo.
Molybdenite		+	+	+	+				Lindgren.
Molybdite							+		
Monazite	+	+	+?					+?	
Muscovite	+	+	+	+	+			+	Lindgren.
Nepheline	+								Rosenbusch.
Niccolite	?				+	+	?		
Noselite	+								
Octahedrite				+				+	8 Van Hise.
Olivine	+		?					+	3 Forsterite, 8 Jahannsen.
Opal					+?	+	+		
Orpiment					+		+		
Orthoclase	+	+	+		+			+	5 var. adularia, 8 Van Hise.
Ottrelite								+	
Pentlandite	+				?				
Perofskite	+							+	Van Hise.

Mineral.	1 Igneous Rocks.	2 Pegmatite Veins.	3 Contact Metamorphic Deposits.	4 Deposits of Deep Vein Zone.	5 Deposits of Moderate and Shallow Depth, Igneous Rocks Nearby.	6 Deposits of Moderate and Shallow Depth, No Igneous Rocks Nearby.	7 Secondary Minerals in Zones of Oxide and Sulphide Enrichment.	8 Products of Dynamo-regional Metamorphism.	Remarks and Authorities.
Petzite					+				Lindgren.
Picotite	+		+						Van Hise.
Platinum	+		+?	?	+?				3 Hundeshagen.
Polybasite					+?		+		5 Spurr.
Proustite					+		+		
Psilomelane						+	+		Penrose.
Pyrargyrite					+		+		
Pyrite	+	+	+	+	+	+	+	+	
Pyrolusite						+	+		Penrose.
Pyromorphite						+	+		6 Rogers.
Pyrophyllite									Weathering at surface.
Pyroxenes	+	+	+					+	
Pyrrhotite	+	+	+	+				+	
Quartz	+	+	+	+	+	+	+	+	
Realgar					+		?		
Rhodochrosite		+			+	+	+		7 L. S. Iron. Leith.
Rhodonite	+	+	+		+				
Riebeckite	+							+?	Van Hise.
Ruby	?	+							2 Hess.
Rutile	+	+	+	+				+	1 Rosenbusch.
Sapphire	+	+	+?						
Scapolite	?	+	+	+				+	2, 3, 4 Lindgren. Possibly surface conditions.
Scheelite		+	+?	+	+				2 and 4 Hess.
Selenite					?	+	+		
Sericite				+	+			+	Lindgren.
Serpentine								+	Van Hise.
Siderite				+	+	+	+	+	7 L. S. Iron. Leith.
Sillimanite		+	+					+	2 Rosenbusch, 3 Calkins
Silver (native)	+?					?	+		3 and 8 Van Hise.
Smithsonite						+	+		
Sodalite	+								
Specularite	+	+	+	+				+	1 Clark.
Spinel	+	+	+	+				+	3 and 4 Lindgren.
Spodumene	+	+							1 Johannsen.
Staurolite			+					+	Van Hise.
Steatite, talc									Surface alteration.
Stephenite					+		+		5 Spurr.
Stibnite			?	+	+				4 Lindgren.
Stilbite				+?				+	
Stromeyerite							+		S. F. Emmons.
Sulphur					?	+	+		5? at surface.
Sylvanite			+?	?	+				Lindgren.
Talc									Surface weathering.
Tellurides			?	+	+				
Tennantite					+				
Tenorite							+?		
Tetradymite					+	?	+		

Mineral.	Igneous Rocks. 1	Pegmatite Veins. 2	Contact Metamorphic Deposits. 3	Deposits of Deep Vein Zone. 4	Deposits of Moderate and Shallow Depth. Igneous Rocks Nearby. 5	Deposits of Moderate and Shallow Depth. No Igneous Rocks Nearby. 6	Secondary Minerals in Zones of Oxide and Sulphide Enrichment. 7	Products of Dynamo-regional Metamorphism. 8	Remarks and Authorities.
Tetrahedrite					+		+?		
Tin (native)							+		7 Hess.
Titanite	+	+	+					+	Also surface weathering.
Topaz	+	+	+	+				+	Also surface weathering, Van Hise.
Tourmaline	+	+	+	+				+	8, possibly 3 and 8.
Tremolite			+	+				+	Van Hise, 4 Lindgren.
Tridymite	+								Near surface only, Van Hise.
Trona									Evaporation, etc.
Turgite and amorphous hematite						+	+	+?	
Turquoise				+?	+?				Zalinsky.
Uralite								+	Also secondary after pyroxene.
Valencianite				?	+				
Vesuvianite			+					+	Van Hise.
Willemite			+?	+?				+	"Probably 3 and 8 combined." Spencer.
Witherite					?	?	+		
Wolframite		+		+					Hess.
Wollastonite			+					+	3, 8 Rosenbusch.
Wurtzite					+		+?		Noelting.
Xenotime	+	+							
Yttrialite		+							
Zeolites	+								All are secondary except some analcite.
Zincblende	?	+	+	+	+	+	+?	?	1 or 8 at Turret, Colo.; 2 at Franklin Furnace, Spencer.
Zincite			+?	?				+	3 and 8 Spencer.
Zircon	+							+	Van Hise.
Zoisite			+	+				+	4 Spencer, also surface weathering.

common associations of minerals such as zincite, willemite, jeffersonite, magnetite, and franklinite, were formed by contact metamorphic process under conditions of exceedingly great pressure such as those which prevail under conditions of regional metamorphism. It is hardly necessary to state that the physical conditions discussed in this paper do not include all conditions under which minerals may be formed and that there may be combinations of and gradations between them. Some minerals which

are known to form as products of surface weathering of igneous rocks are referred to briefly in the ninth column, which in many instances includes also the names of investigators upon whose authority the classification is made.

The minerals which appear to have been formed under all the conditions named are quartz, pyrite, chalcopyrite, apatite and probably gold. For these Lindgren has proposed the name "persistent minerals." Clear crystalline quartz is much more abundantly formed in areas of igneous rocks or under contact or dynamo-regional metmorphic conditions, but clear crystalline quartz is also deposited by cold surface waters, as is indicated by the large crystals lining geodes in sedimentary rocks which appear to be far removed from igneous activities. Yet as a rule the silica which is deposited with ore minerals far from igneous rocks or in processes of secondary enrichment is much more likely to be the chalcedonic or cherty variety. Gold is widely disseminated since it occurs in traces in igneous rocks where it is believed to be a primary constituent and traces of it seem to have been precipitated in rocks which are remote from igneous outcrops. Apatite is secondary in Superior iron ores.

The tables indicate that a number of minerals are formed where lavas crystallize to form igneous rocks but not under the other conditions named. These are aegerite, arfvedsonite, cancrinite, haüynite, native iron, leucite, melilite, nepheline, noselite, riebeckite? and tridymite. The list is very small compared with a complete list of rock-making minerals.

Perhaps the fact is significant that nearly all of these minerals are rich in soda. While these soda minerals are not as a rule abundant in igneous rocks they have not been reported from any deposits of the other divisions. Lindgren[1] has pointed out the instability of soda salts in the veins formed at moderate or shallow depths. Albite, it is true, is formed in deep veins, in contact metamorphic deposits, and in pegmatites, but with this exception soda minerals are almost unknown in veins. Of the soda-rich minerals named above, all except nepheline contain either iron, chlorine, CO_2 or SO_4. It should not be expected that solutions

[1] ECONOMIC GEOLOGY, Vol. II., p. 117.

rich in soda and in the other elements named should be able to deposit from aqueous solutions, presumably dilute, the highly soluble salts which these elements form. It seems that they may be fixed in an igneous rock if the magma cools in such a manner as to prevent their escape to the surface, but there is a strong tendency for soda to join the general circulation and be carried to the sea when it does escape from the cooling magmas.

There seems to be strong ground for the presumption that some minerals reported to occur in igneous rocks are in the intensely metamorphosed products of fragments of sedimentary rocks caught up in the igneous magma. This is probably true of andalusite and ilvaite; possibly of actinolite and other minerals.

Spodumene and xenotime are the only minerals listed which are limited to igneous rocks and to pegmatite veins but which are not reported from deposits formed under other conditions.

Aquamarine and yttrialite are the only minerals listed which are confined to pegmatites, but, as already stated, this list is probably large since a number of other rare minerals seem to form only under such conditions.

Of the minerals which are formed under contact metamorphic conditions but under no other conditions, the humites are the only representatives listed. It is noteworthy that while the associations of minerals which go to make up contact metamorphic deposits are characteristic and unique the minerals themselves are almost altogether those which may be formed also under other conditions. Some of them are formed also in the igneous rocks. Others are formed also under regional metamorphic conditions and still others are formed in the metalliferous veins. Staurolite, vesuvianite and wollastonite are probably limited to contact metamorphic deposits and to dynamo-regional metamorphic deposits.

The minerals of the deep vein zones are not limited to that zone. Some of them are formed under contact metamorphic conditions, in pegmatites and in igneous rocks, while others are formed in metalliferous veins which were formed at moderate depth. The associations of minerals are characteristic but the individual species are not.

There is a large group of minerals which is formed in igneous rocks, in pegmatites, in contact metamorphic deposits under regional metamorphic conditions, and in the deep veins, but not in the other groups of the deposits named. These are albite, amphiboles, biotite, diopside, garnet, graphite, hornblende, ilmenite, pyrrhotite, rutile, scapolite, specularite, spinel, topaz and tourmaline. Possibly epidote and andradite should be added to this group.

The minerals listed as having been formed in deposits of moderate and shallow depth associated with igneous rocks and which are probably primary in such deposits, but which have not been found in ore deposits in sedimentary rocks remote from igneous activities are: Argentite, arsenopyrite, bismuthinite, calaverite, cerargyrite, cinnabar, cobaltite, enargite, kalgoorlite, molybdenite, muscovite, orpiment, orthoclase, petzite, proustite, pyrargyrite, realgar, rhodonite, scheelite, sericite, stephenite, stibnite, sylvanite, tellurides, tennantite, tetrahedrite, tetradymite, turquoise and wurtzite.

Possibly all of the following minerals are deposited both by primary and secondary processes in veins associated with igneous rocks and not under other conditions: Argentite, cerargyrite, cinnabar, enargite, orpiment, polybasite, proustite, pyrargyrite, realgar, stephenite, tennantite, tetrahedrite.

Our knowledge of the mineralogy of secondary deposits is so unsatisfactory that little confidence can be placed in the last list. The arsenic and antimony sulphides of copper and silver are often present in greater or less amount in veins of moderate and shallow depth associated with igneous rocks. Some of these minerals, such as pyrargyrite, are doubtless both primary and secondary, but hard and fast lines can not yet be drawn. It is noteworthy that these minerals do not enter into the composition of such ores as the zinc ores of southwest Missouri and southwest Wisconsin, which are remote from igneous deposits and which seem to have no connection with igneous agencies, but, since it is known from studies of secondary enrichment that cold sulphate solutions may deposit some of them, possibly they will

yet be found in other conditions than those indicated in the tables.

Minerals which are deposited in veins of moderate and shallow depth associated with igneous rocks and which are probably primary altogether in such deposits are: arsenopyrite, bismuthinite, calaverite, cobaltite, fluorite, kalgoorlite, molybdenite, muscovite. orthoclase, petzite, rhodonite, stibnite, sylvanite, tellurides, tetradymite, turquoise.

Minerals which are secondary in deposits associated with igneous rocks, but which are not known to be primary, are: Alum, amalgam, anglesite, antimony, apophyllite, arsenic, atacamite, aurichalcite, azurite, bismuth, bromyerite, calamine, caledonite, calomel, cerussite, chalcanthite, chrysocolla, covellite, cuprite, goslarite, gypsum, hydrozincite, lead, leadhillite, limonnite, malachite, manganite, melaconite, mercury, molybdite, psilomelane, pyrolusite, pyromorphite, smithsonite, stromeyerite, tin, turgite.

Very few sulphides are known to be limited to secondary deposits. Perhaps covellite is restricted to this group and by far the larger proportion of chalcocite is deposited by processes of secondary enrichment. As already stated, some of the sulphantimonates and sulpharsenates named may also belong to the group of exclusively secondary minerals.

There is not one mineral which may be said to be characteristic of deposits which are far removed from outcrops of igneous rocks. The ore of such deposits is usually very simple mineralogically and all the minerals of which it is composed are also found in deposits associated with igneous rocks or in the secondary products of such deposits.

The minerals which are listed as occurring as products of secondary enrichment or of alteration in deposits associated with igneous rocks, and which are also either primary or secondary minerals in deposits far removed from outcrops of igneous rocks, but which are not primary in deposits which are associated with igneous rocks, are: Alum, anglesite, aragonite, aurichalcite, azurite, calamine, caledonite, cerussite, chalcanthite, chrysocolla, covellite, cuprite, goslarite, hydrozincite, leadhillite, limonite, mala-

chite, manganite, pyrolusite, pyromorphite, selenite, smithsonite, turgite.

Among the secondary minerals[1] formed in the Lake Superior iron oxide zones are adularia, analcite, aphrosiderite, masonite and rhodochrosite. These minerals together with some products of surface weathering of igneous rocks are not formed as secondary products in ordinary lode deposits. A further subdivision of this column is desirable. Apatite, goethite, pyrolusite and siderite are formed in the oxide zones of Lake Superior iron deposits, but these four minerals are also primary in the iron ore sediments.

Minerals which are secondary in veins associated with igneous rocks, and which are probably not primary in such deposits and which are not listed in deposits which are not associated with igneous rocks, are: Amalgam, antimony, apophyllite, arsenic, bismuth, bromyrite, calomel, lead, mercury, molybdite, stromeyerite, tin.

Of the minerals which are known to form under conditions of dynamo-regional metamorphism and which are not known to form under other conditions anthophyllite and ottrelite are the only ones listed. The conditions of deposition seem to be such that the same minerals are formed as those which are formed under contact metamorphic conditions, although quantitatively there is probably a very great difference in the mineral products which result from the two sets of metamorphic processes.

In conclusion it may not be out of place to state that the tables are not regarded as approaching finality, but perhaps they may serve as a basis for continuous revision and correction by those who are interested in the subject.

[1] C. K. Leith, private correspondence.

THE RELATION OF COPPER TO PYRITE IN THE LEAN COPPER ORES OF BUTTE, MONTANA.

JAMES F. SIMPSON.

Recent studies in the order of formation or paragenesis of the metallic ore minerals whose relations cannot, on account of their opaque character be studied in thin section, have led to interesting results in a number of localities. It has long been a disputed question whether copper in lean pyritic ores—the supposed primary source from which many richer copper ores are believed to have been derived—is present as a definite copper mineral or in chemical combination with the pyrite. The methods employed in previous studies of polished surfaces by reflected light seemed to the writer applicable to the solution of this problem as exemplified by certain of the leaner ores of Butte, Montana. It is, therefore, the purpose of this paper to set forth the results of an investigation of these lean pyrite ores; results which are sufficiently definite to warrant careful presentation.

Exactly stated the problem is to determine whether the copper in the Butte ores forms a chemical compound or mechanical mixture with the pyrite, when there is an extremely small percentage of copper present. It has been generally accepted by those familiar with these ores that the copper is chemically combined, the ore being, therefore, cupriferous pyrite instead of a combination of pyrite and bornite, chalcocite, enargite, or chalcopyrite, according to which copper compound is present.

The only way to attack this problem successfully is by the microscopic examination of polished surfaces of specimens of the ore, using reflected light. Under the microscope, this surface shows the relations of all the constituents, as a thin slide shows the relation of transparent minerals.

This method is called "Metallography," and is used fre-

quently at the present time. Papers have been written on both the methods of procedure and results of studies by William Campbell and C. W. Knight, both of the Columbia School of Mines, New York. Throughout this work, the method as set forth by William Campbell has been followed and due acknowledgment is hereby given him.

PREPARATION OF SAMPLES.

A chip about an inch square and one quarter inch thick can easily be broken off a hand specimen of the ore to be studied, and trimmed and smoothened on an emery wheel. Then the face can be still further smoothened on a grindstone, after which it is ready for the polishing machine. This consists of a horizontal leaden wheel, or lap, driven by a motor and surrounded by a shield to catch the water thrown off during the operation of polishing. Emery powder is placed on the lap and moistened, and the specimen is held against the rapidly revolving wheel. Several grades of the powder must be used, each one eradicating the scratches of the previous powder. Care must be taken that no particle of powder is mixed with the next finer grade, for if this happens, the specimen will be badly scratched. After the finest grade of emery powder has been used, the specimen is polished on a sheet of plate glass, by means of rouge. To save the work of mounting, the under side of the specimen can be ground flat and parallel to the polished side, on the emery wheel.

MICROSCOPE AND ILLUMINATION.

A Nachet microscope was used on this work, and for magnifications of less than 225 diameters, ordinary sunlight gave sufficient illumination. For higher power work than this, a Welsbach light was necessary, and the microscope then had to be fitted with a vertical projector.

SAMPLES.

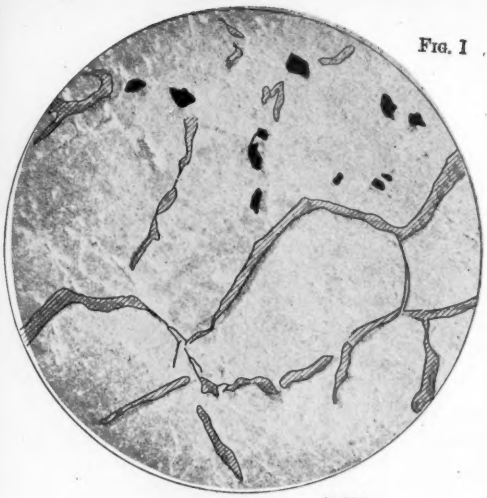
The samples used were selected from a number sent from the copper mines at Butte. Only those which showed no copper mineral to the naked eye were used, for it was desired to find

EXPLANATION OF PLATE X.

FIG. I. Rough, badly scratched pyrite intersected by veinlets of bornite and containing a few small flakes of chalcocite embedded in the pyrite.

FIG. II. Rough, badly scratched pyrite intersected by veinlets of bornite.

FIG. I



X 300

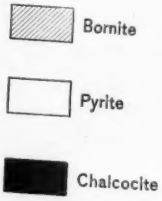
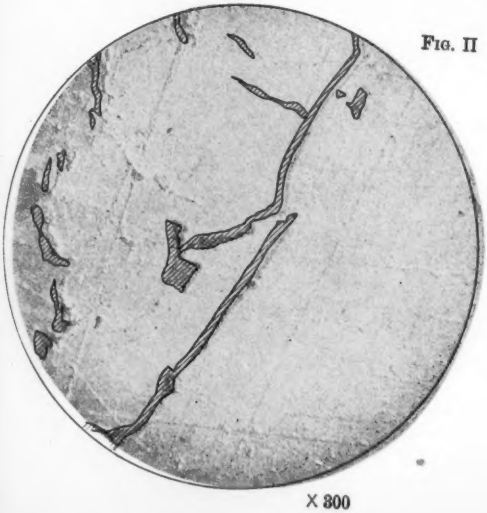


FIG. II



X 300

the relation of the copper to the pyrite in those ores in which the existence of definite copper minerals was unknown. It would, of course, be desirable to know whether the ore samples used represented ores of primary deposition, or ores largely produced by secondary enrichment. It is very difficult to distinguish between the two classes of ores in Butte at the present time, but Mr. R. H. Sales, geologist of the Amalgamated Copper Co., believes that the samples which he sent from the Mountain Con. Mine represent portions of the original vein filling.

OPAQUE CONSTITUTENTS OF THE ORES, AND MEANS OF IDENTIFICATION OF EACH.

The chief constituent of the ore is pyrite; associated with this is chalcocite, chalcopyrite, bornite, or enargite, as the case may be, and each is distinguished under the microscope by the following characteristics:

Bornite.—$3Cu_2S.Fe_2S_3$. Copper red to pinchbeck brown in color. H. = 3. Easily attacked by nitric acid. This acid gives the bornite a tarnished appearance. When with pyrite, an extremely smooth surface of this mineral is difficult to obtain, on account of the great difference in hardness between the two.

Chalcocite.—Cu_2S. Blackish to lead-grey in color. H. = 2. When etched with nitric acid, a distinct blue color is obtained. This is the best means of identification.

Chalcopyrite.—$CuFeS_2$. Color, brass yellow. H. = 3.5–4. The color is the best characteristic. Soluble in nitric acid.

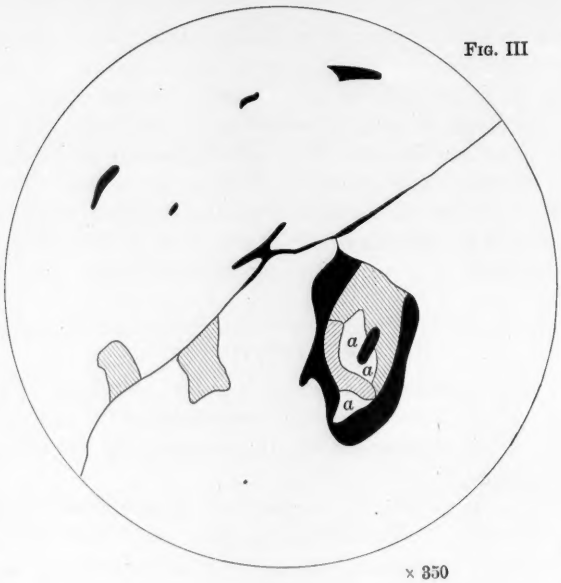
Enargite.—Cu_3AsS_4. Color steel grey to greyish-black. H. = 3. Soluble in aqua regia only. Its insolubility in nitric acid is the best means of distinguishing it from chalcocite.

Pyrite.—FeS_2. Its pale brass-yellow color is one of the best means of identification. On account of its hardness, it retains scratches long after the other constituents. H. = 6–6.5. Etched by nitric acid.

From the above, it can be seen how the differences in color, action of the acids, and perfection of polish can all be used to identify and distinguish the different minerals in this study.

PLATE XI

FIG. III



× 350

Enargite

Chalcopyrite

Pyrite

Chalcocite

"a" "Cavity"

FIG. III. Lean pyrite from Alex Scott Mine 800 feet below the surface. Carries 0.5 per cent. to 10 per cent. Cu. The main mass is well crystallized pyrite, with enclosed quartz crystals. Enargite, chalcopyrite and chalcocite also occur in tiny veinlets. To the right and below the center chalcocite occurs enclosing enargite and chalcopyrite about a central cavity. Cu = 0.41 per cent. to 4.835 per cent.

FIG. IV

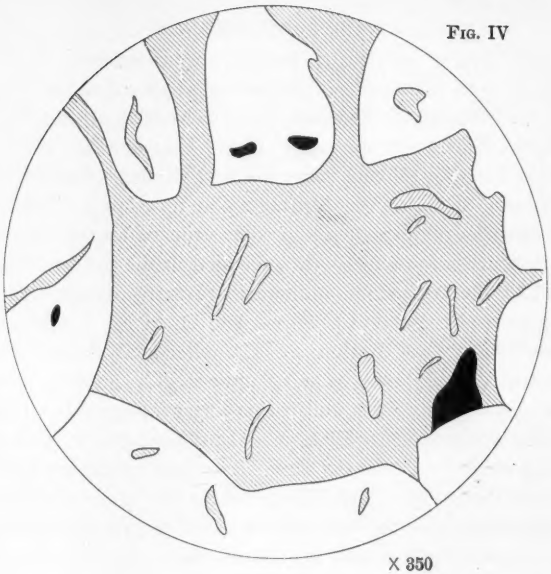


FIG. IV. Specimen from Original mine. Consists of pyrite enclosing quartz crystals. The center is a mass of bornite with inclusions of chalcopyrite and chalcocite. Cu = 0.626 per cent.

RESULTS OF STUDIES.

The following specimens were kindly furnished by R. E. Davis, of the Pittsburgh and Montana Copper Co. (Nos. 2 and 5); C. T. Kirk, of the Montana State School of Mines (No. 3); and R. H. Sales, of the Amalgamated Copper Co. (Nos. 1, 4, and 6). These specimens were the best of those studied.

Specimen 1.—Mt. Con. Mine. 2,000 foot level. This specimen contains a number of microscopic veins of bornite and a few small flakes of chalcocite, both embedded in the pyrite (Plate X, Fig. 1). The two copper minerals are easily distinguished by their color and the action of nitric acid on each. It can be seen that the veins are not continuous. Complete analysis of the specimen gave: Cu, 2.41 per cent.; gangue (SiO_2), 2.68 per cent.; sulphur, 49.26 per cent.; and iron, 45.23 per cent. Total, 99.58 per cent. Sample (*b*) (Plate X, Fig. 2) from the same hand specimen as above shows the same occurrence of the bornite with relation to the pyrite. The analysis checks very closely, being: Cu, 2.48 per cent.; gangue, 2.10 per cent.; S, 49,50 per cent.; and Fe, 45.70 per cent. Total, 99.78 per cent.

Specimen 2.—Alex Scott Mine, about 800 feet below the surface. In ton lots the ore runs from 0.5 per cent. to 10 per cent. copper; 13 per cent. silica, and the iron varies. The main mass is well crystallized pyrite, with enclosed quartz crystals. Enargite, chalcopyrite, and chalcocite are present in small grains. The chalcocite also occurs in tiny veinlets. In one place the three copper minerals are found together, the chalcocite enclosing the other two (Plate XI, Fig. III). Analysis of the copper (battery method) gave: Cu, 0.41 per cent., and quartz, 4.835 per cent.

Specimen 3.—Original Mine. This specimen is composed mainly of quartz crystals included in the pyrite. Veins of bornite cut both in places. In the bornite, there are a few inclusions of both chalcopyrite and chalcocite. There is present in this specimen a small patch of bornite which may be seen with a hand lens. Plate XI, Fig. IV, shows this occurrence, and also the relation of the three copper minerals to each other. Analysis for the copper gave: Cu, 0.626 per cent.; quartz, 59.20 per cent.

Specimen 4.—Mt. Con. vein, near Bell Fault. 1,800 foot level.

There were only one or two occurrences of copper in this specimen. There were many cracks in the pyrite, which filled with emery powder from the grinding. (Plate XII, Fig. 5) shows the chalcocite, and also the cracks, which in the photograph might be mistaken for copper veins. Analysis for copper gave: Cu, 0.086 per cent.; gangue, 4.2 per cent.

Specimen 5.—Mt. Con. Mine. Syndicate Lode. 2,000 foot level. There are present a few occurrences of chalcocite in the form of microscopic spots, enclosed in the pyrite (Plate XII, Fig. 6). Analysis showed there was 0.201 per cent. copper present.

Specimen 6.—Diamond Mine. 1,200 foot level. Numerous good-sized veins of quartz run through the pyrite. No copper mineral of any kind was seen in this specimen by means of the microscope, and none could be found by chemical analysis.

CONCLUSION.

From this metallographic examination of the lean copper ores, there are four facts which stand out clearly, namely:

1. Copper minerals can be detected microscopically in all the samples whose chemical analysis reveals copper.

2. The copper minerals thus present within or associated with the pyrite are chalcocite, bornite, chalcopyrite and enargite.

3. The order of deposition of these minerals in the ore is: Chalcopyrite, enargite and bornite, chalcocite. The enargite and bornite are closely associated, and from the specimens at hand, the exact order of deposition of these two could not be determined.

4. Copper is absent from specimens containing no copper minerals.

Therefore the copper is not present in chemical combination with the pyrite of the lean Butte ores, but on the contrary, it is present intimately associated with the pyrite in definite copper minerals of four kinds (chalcocite, bornite, chalcopyrite, and enargite) and these minerals occur in a definite order.

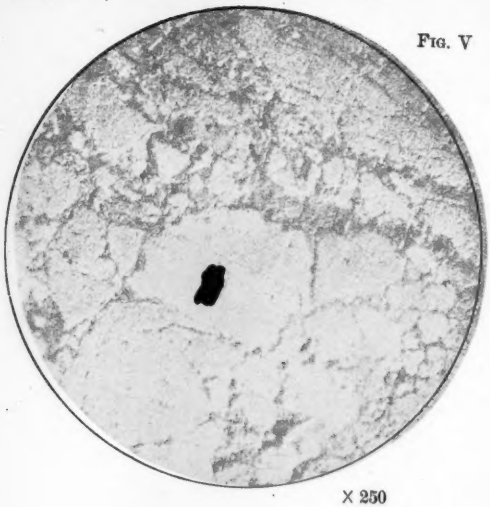
The writer is indebted for many valuable suggestions to the assistance and criticism of Dr. A. N. Winchell.

EXPLANATION OF PLATE XII.

FIG. 5. Very lean copper ore from 1,800-foot level of Mt. Con vein near Bell Fault. Specimen consists almost wholly of pyrite. One spot of chalcocite is seen a little below the center of the slide. The dark cracks are cracks in the pyrite filled with emery powder from the grinding. This specimen showed on analysis 0.086 per cent. Cu.

FIG. 6. Lean copper ore from Mt. Con Mine. Specimen consists of pyrite with irregular blotches of chalcocite in it. Analysis shows 0.201 per cent. Cu.

FIG. V



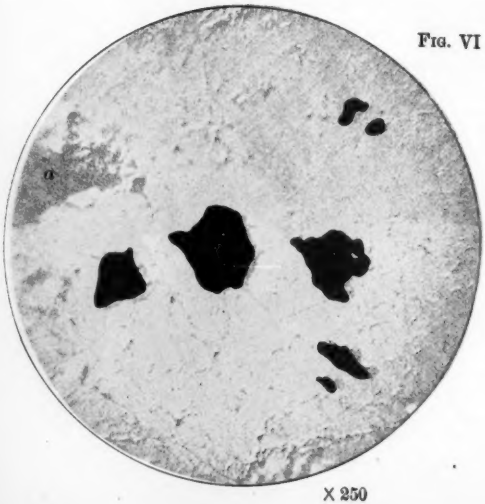
X 250

Chalcocite

Pyrite

"a" = Cavity

FIG. VI



X 250

This
those i
informa
of disc
upon m
Sheffiel
name o

THE

Sir
Occur
contri
silver
centur
in the
To
of the
copper
The
not as
navian
that a
ing th
moved
sula a
parts
in this
The
tory o
of the

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE LOCALIZATION OF VALUES IN ORE BODIES AND THE OCCURRENCE OF SHOOTS IN METALLIFEROUS DEPOSITS.

Sir: To the discussion on "The Localization of Values and the Occurrence of Shoots in Metalliferous Deposits" I will hereby contribute a few notes concerning Scandinavian copper and lead-silver mines. As several of these mines have been worked for centuries, our knowledge of the distribution of the value of metal in the different parts of the deposits is based on long experience.

To begin with, I will illustrate a few instances of the decrease of the copper percentage with depth in some of the principal copper-mines in the Scandinavian peninsula.

These occurrences we must consider as primary features and not as secondary enrichments. The rock-surface of the Scandinavian peninsula was, during the glacial time, so deeply eroded that all products of surface weathering, which had gone on during the greater part of Mesozoic and Cainozoic time, were removed by the ice. The ore deposits of the Scandinavian peninsula are thus in general to be considered as the roots or the deeper parts of the original deposits now laid open for observation and in this respect they claim a special interest.

The famous Falu mine is a case at hand. This mine, the history of which can be followed for 750 years, had, until the end of the nineteenth century, yielded more copper than any other

separate mine in the world. During this time the mine has produced, in round numbers, 500,000 tons of copper, 15 tons of silver and 1 ton of gold, representing a sum of about 1,000 million Swedish crowns (about $27,000,000).

The pyrite occurs enclosed in a quartzitic rock derived from the surrounding granitic gneiss which is Archaean. This metamorphism, which probably took place in connection with the formation of the ore, consisted in the solution of the greater part of the basic constituents of the granite (alkalies and alumina), so that the remaining rock consists almost exclusively of silica. The ore-bearing rock is traversed by eruptive dikes, acid as well as basic, of felsitic and dioritic nature. A connection between them and the formation of the ore has not, however, been ascertained.

The largest ore-bodies at Falun are stocks of pyrites of conical form with points downwards. The largest of these stocks ceases at the rather moderate depth of 332 m.; no continuation of it has been found. The pyritic ore-bodies are enclosed in peculiar rock-masses consisting chiefly of talc and chlorite ("skölar") and carrying several minerals of secondary origin. The "skölar" enclose the conical ore-bodies and separate them from the surrounding quartzite; they thus get a shape which may be compared with cornets, filled with the pyritic masses.

The distribution of the rich copper ore was chiefly close to the inner side of the "skölar" and in the "skölar" themselves. Their central parts contained much less copper. There is also a general decrease of copper towards depth; *i. e.*, the point of the cornet is evident. In the Falu mine as well as in most old mines one at first worked the richer parts of the deposit, *i. e.*, the upper and the peripheries adjoining the "skölar," leaving the more central parts.

In recent years an ore containing about 3 per cent. Cu has been mined, and the ore percentage has been 33 per cent., *i. e.*, the average amount of Cu obtained from the mined rock has been 1 per cent. In the older parts of the mine, according to tradition, a far richer ore has been obtained. The very large quantities of

copper produced in former times also prove that a considerably richer ore was then mined, probably containing 10 per cent. of Cu or more; otherwise an annual production of more than 3,000 tons of copper would have been impossible. The maximum production is recorded for the year 1650, when it amounted to 3,067 tons.

A similar case is presented by the mines at Åtvidaberg, which also had their palmy days in past centuries and were abandoned in the seventies of last century. The Bersbo mine, where the deposits are now being explored at a depth of 410 m., and the Mormors mine, which, when being abandoned, had reached a vertical depth of 407 m., are now the deepest mines in Sweden. The ores, which in the Bersbo mine occur at the contact with a diorite body, consist of copper pyrites, pyrrhotite and sphalerite in a quartzose gangue. In this mine the decrease with depth both of the dimensions of the veins and of the copper percentage of the ore is observed. A striking feature in the Bersbo mine is the downward increase of the zincblende with proportional decrease of copper.

The above two examples are taken from among deposits of the Archæan system. Instances of the same kind regarding the decrease of the copper percentage with depth are afforded by the numerous pyrite deposits associated with gabbro and occurring within the metamorphosed Silurian schists that constitute a great part of the high mountains of the Scandinavian peninsula. Such an instance is Vigsnäs on the western coast of Norway, a fairly great deposit, which was in a forced manner exploited in about thirty years, from 1865 to 1894, during which period the mine yielded 850,000 to 900,000 tons of pyrites and copper ore. The deposit consists of a system of veins in gabbro, which rock in the parts adjoining the veins is altered into a schistose chloritic rock. In the upper parts of the deposit the average copper percentage was 2 per cent. to 2.25 per cent., which percentage, however, decreased rather regularly with depth, being at the greatest depth attained, 735 m., reduced to less than 1 per cent. On the whole, the deposit was worked only to the depth of 600 m., but though

the dimensions of the pyritic bodies were nearly the same even at the depth of 735 m., they were left unworked, because the copper percentage had sunk below the limit of workableness.

Vigsnäs is a deposit with a high dip—at least 70°. The numerous deposits of the same type that have a flat position, *i. e.*, that have a dip of only a few degree, present different features from those of Vigsnäs with respect to the copper percentage. In them no decrease of the copper is observable, when followed in the direction of the dip even to a considerable length.

The mines of Rörås and Sulitelma offer instances of this. In the former of these mining districts where one can look back on a period of 250 years of mining, the pyritic bodies have been followed, in the Storvarts mine, 1,350 m. with a dip of 8°–10°. In the Mug mine also with an average dip of 8°–10° the ore-body has been followed 1,080 m., and in the King's mine (Kongens Grube) in which the ore lies partly horizontal, and where in places it has a very slight inclination, the deposit has been followed no less than 2,000 m. in the direction of the dip, without any observable change as to the copper percentage of the pyrites. At Sulitelma the case has been found to be the same, though the ore-bodies there have a somewhat greater dip than at Rörås, not amounting, however, anywhere to 30°.

It thus appears that there is a decided difference in the aforesaid respect between deposits with a low degree of inclination (30° or less) and such as have a steeper dip, the copper percentage of the former continuing the same with depth, while in the latter it decreases rather rapidly as the deposit is followed downward. This rule is valid with regard to the deposits in Archaean rocks (Falun and Åtvidaberg) as well as to those of Silurian (Vigsnäs, Rörås, Sulitelma) and therefore seems to be universal.

This fact can, according to my view, be accounted for only by assuming the copper value in the said deposits to be a function of the *vertical* depth and the formation and precipitation of the copper substances from the magmatic solutions to have been dependent on the hydrostatic pressure that existed at different levels below the surface as it was when the ores were formed.

The above circumstances are evidently not only of great theoretical interest, but of equally great practical importance. For it is obvious that in the valuation of a pyritic deposit of this type one must attach a far greater importance to the inclination of the deposit than has hitherto been usual. It follows from the above that a pyritic deposit of this type, other things being equal, must be considered of higher value, if it has a flat or slightly inclined position, than if it stands more vertically.

Also with regard to the lead and silver mines, experience warrants the same conclusion. The oldest and most important silver mine in Sweden is the Sala mine, which has been worked for more than four centuries on a metasomatic deposit in dolomitic limestone. The mineralization obviously started from a system of fissures (skölar) which with depth join in a trunk fissure (the Great sköl), which traverses the deposit longitudinally. The percentage of lead has, on the whole, notably decreased downward, so that no more sinking work has been carried on during the last twenty years, the greatest depth being now 320 m. The mining is going on exclusively on higher levels in such portions of the ore as were formerly regarded as too poor to raise, but which, however, are richer than the lower portions of the deposit in general. With increasing depth a general "dilution" of the deposit through dolomitic limestone is observable. The silver value has decreased in a still higher degree than the lead percentage; the rich silver minerals which, together with argentiferous galena occurring on the higher levels, viz., silver amalgam, argentite and native silver, not being found at greater depths.

Another deposit of similar nature, though of smaller extent, is the lead-silver mine of Kallmora, Wästmanland, which has been worked on an argentiferous galena lying in limestone. Even at a depth of about 200 m. this deposit was found to be so strongly "diluted" with lime that the working had to be abandoned.

A very interesting instance of decreasing percentage of metal with depth is afforded by the silver mines of Svenningdalen in Norway. They were worked on a system of parallel veins

traversing at right angles a series of schists and limestone beds of Silurian age, as well as an intrusive granite. The argentiferous minerals in Svenningdalen are, besides a galena, containing about 1.5 per cent. Ag, fahlores rich in silver and proustite.

The two accompanying diagrams, illustrating the decrease of the silver value in two of the mines were made by the mining engineer, O. Witt, who has been kind enough to place them at my disposal (Figs. 63 and 64).

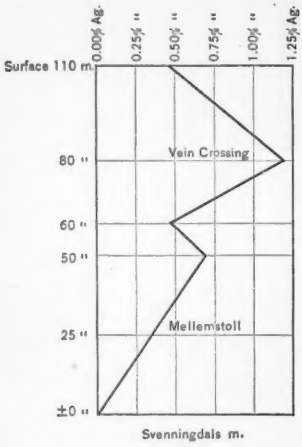


FIG. 63.

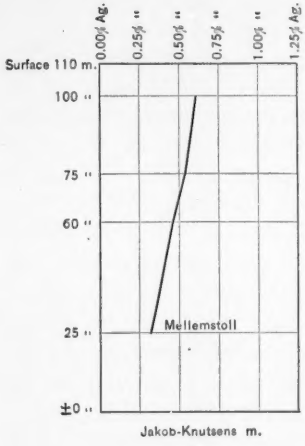


FIG. 64.

As the system of veins in Svenningdalen has been followed only to a depth of 100 m., it might be supposed that the decrease of the metal percentage at that depth is but accidental, but the fact that the same relations occur in the two mines, the Svenningdals and the Jakob Knudsens, indicates that it is not accidental.

The mines of Svenningdalen also offer obvious instances of the enriching influence of vein-crossings; a rich "bonanza" was found in the crossing between the main vein of the Svenningdal mine and the so-called southwest vein. Also in the Jakob Knudsen mine it has been observed that the values are richest at the vein-crossings.

From the copper and lead-silver ores here mentioned the Swedish iron ores differ with regard to the constancy of the metal percentage; in these ores no general decrease of the iron with depth has been shown. These ores, so far as they belong to the Archaean formation, are referred to two classes.[1] One class comprises ores associated with basic eruptives of the gabbro group; they are products of magmatic differentiations, which have taken place in the rock magma *in situ*. Owing to their high percentage of titanium and their often low percentage of iron, they offer great difficulties to the metallurgist, and though there are vast supplies of these ores, they are as yet of no commercial value. For the ores of the other class, which occur associated with metamorphosed quartz-feldspar rocks of eruptive character such as granulite, hälleflinta, syenite porphyries, etc., I have proposed the name "dia-magmatic." They are evidently genetically connected with the aforesaid quartz-feldspar rocks, but have been produced through a differentiation process in a deeper zone, by which the iron-magnesia-lime-bearing material has been segregated from the silica-alumina-alcali material and, kept in solution through water and other mineralizers, at the later stage has formed epigenetic deposits. This is the same type to which C. K. Leith in his interesting paper[2] recently has proposed the name "pegmatite type."

Ores of these classes have, it is true, undergone changes in the surface zone affecting the degree of oxidation of the iron; moreover, the minerals of the pyroxene and garnet groups have given rise to amphiboles, and epidote, chlorite and talc minerals, but on the whole the ores show no changes with regard to richness and metallic value towards the depth. If, as is frequently the case, individual ore-bodies cease even at slight depths, they are in such cases followed by others of the same character.

HJALMAR SJÖGREN.

[1] Compare: "Geological Relations of the Scandinavian Iron Ores," *Transact. of the American Institute of Mining Engineers,* Vol. XXXVIII., p. 766, 1907. Reviewed on page 658, this JOURNAL.

[2] ECON. GEOL., Vol. III, p. 277.

BROKEN HILL SILVER MINE, NEW SOUTH WALES.

Sir: Having recently spent a week at Broken Hill Silver Mine, N. S. Wales, I am preparing a short note on its occurrence for ECONOMIC GEOLOGY. The following is a summary of the note:

Several geological facts become at once apparent upon even a cursory examination of the field. Thus:

1. The Broken Hill area is a mass of crystalline schists and allied rocks all possibly pre-Cambrian in age. Garnets and sillimanite are characteristically developed; pegmatites and quartzose masses also form irregular segregations or lenses along planes of schistosity. Replacement of schists by pegmatites is a common feature.

2. The general strike of the schists is remarkably uniform, being approximately in a northeast and southwest direction.

3. The outcrop of the Broken Hill Lode has the same strike as the country rocks.

4. Three belts of schists occur in immediate association with the lode, viz.: (*a*) A belt of dense gneissic rocks and amphibolites forming its eastern wall. (*b*) A similar belt forming the western wall. (*c*) A soft weak and well-laminated series of mica schists, and allied rocks, some ten chains in width, alongside of, and through which, the Broken Hill ores occur.

5. At the surface, and in the open cuts, the lode appears to partake of the nature of a fissure developed along a plane of schistosity. At certain places along the lode outcrop the weak schist mass of the Hanging Wall is highly contorted; nevertheless no sympathetic foldings of the schists forming the associated dense country are observable.

The weak schist mass never leaves the fissure, but preserves the same general strike as the latter with marked local deviations from this direction. In general aspect it is analogous to a roof of corrugated iron which has the same general strike and dip as that of the frame to which it is attached, and yet has numerous puckerings or corrugations causing marked local deviations from the general strike.

6. The ore masses apparently are developed to the west of the

fissure. An exception to this appears to occur in the Proprietary Mine.

7. The ore masses are, notably, replacements: (*a*) Along the fissure itself. (*b*) Along weak layers in the schist corrugations. Such shoots of ore have steep southwesterly pitches to the south of Block 14, and a steep northeasterly pitch to the north of the same property.

8. At first sight the "shoots" are strikingly suggestive of "saddle" reef formations. They, apparently, curve sympathetically with the corrugated foliation planes.

9. The so-called "saddles," however, are intimately related to the fissure or "footwall"; they are generally continuous with it on one side—appearing to spring out of it—and though their longer axes are not strictly in the same plane as that of the "footwall" or fissure, they are so intimately related to it as to suggest their absolute dependence on it for their existence.

10. The "saddles" do not occur in the strong schist belts, and are not found outside of the weak crumpled zone. Underneath the "shoots" or "saddles" the foliation planes exist in anticlinal form, ore and country having a similar general curvature. They do not, however, represent filling of fissures formed between folded planes, but represent rather the replacement of huge masses of weak schist structures; for throughout the huge stopes abundant traces of the numerous foliation planes may be seen right through the ore masses. "Horses" of "mullock" occur completely surrounded by ore, yet so disposed as undoubtedly to represent remnants of crumpled schists *in situ*, and not fragments filling fissures.

On the upper portions of the "saddles" the ore commonly grades into the country.

11. The fissure is not characteristic of the "zone of fracture." It is rather insignificant in itself and is important only by reason of the intense activity of the solutions which rose along it. The ore associates also point to a deep-seated origin for the lode. Thus garnets, rhodonite, secondary mica, and quartz are abundantly represented. Fluorspar also occurs.

Deductions.—A series of rocks occupying the Broken Hill

area had been changed to crystalline schists. Garnetiferous schists, pegmatites and amphibolite had been developed while basic cross dikes had been altered also into schists. One belt of weak, well-laminated mica schists and allied rocks had been developed between two very resistant series. Either the intensely laminated appearance of this weaker belt was due to original structural weakness or, as seems more probable, to shearing of two dense rock series on each other. Later a narrow but strong fissure was formed along this line of weakness (plane of schistosity). A rotatory movement apparently now acted powerfully on the weak schist buffer. Strong parallel corrugations were developed in it. These same were arranged vertically under each other north and south of Block 14, and their main axes lay mainly in planes approximately parallel to, and alongside of, that of the fissure. Individual corrugations represent so many flexings of the *same* schist belt. Heated waters—or water and water vapors—rose along the fissure and replaced the weaker schist folia of the associated corrugations. In presence of great pressure and strong reagents (hydrochloric, hydrobromic, hydrofluoric and other acids), they simultaneously attacked the weaker walls of the main fissure and the intensely laminated folia of the corrugations. The stronger layers offered greater resistance to percolation of the waters and thus a "saddle"-like set of ore masses was developed. Firstly an intense silication occurred with later great development of amazonite, rhodomite, garnet, also zinc, lead and silver sulphides. In many cases an imperfect replacement occurred, thus permitting the tracing of the various stages in replacement.

The geological permanence of this field is thus suggested. The economic side of the question cannot be satisfactorily discussed until the *corrugations* (and the fissure) so far exposed by actual mining operations have been carefully examined so as to apprehend the scheme of crumpling—if any such exist—and the class of schist or schist structure most amenable to replacement. A knowledge of the varying quality and character of the ore bodies with depths so far obtained is also necessary.

E. C. ANDREWS.

MT. MORGAN, QUEENSLAND,
May 25, 1908.

THE CLASSIFICATION OF LOW GRADE COALS.

DISCUSSION OF PAPER BY M. R. CAMPBELL.

Sir: Considerable interest is now shown in the subject of Mr. Campbell's recent paper, and I fear that misunderstandings may arise from some of the statements in it.

As a basis for distinction of some classes of coal, Mr. Campbell uses "weathering," which he judges by (1) cleavage, (2) fracture on drying, (3) the separation into thin plates on weathering. He adds other distinctions for lignites and cannels, but the main contribution seems to be the use of weathering. He bases his groups on type examples which he describes, illustrates, and names, noting, moreover, that there are all intermediate types between those given.

But the three points above, on which he judges a coal, are not stated in his paper with any approach to quantitative accuracy. In fact it would be difficult for anyone to make a quantitative distinction on such properties which would be capable of experimental determination. Take the case of cleavage for example. The openings in a coal by which gases may escape (all of which he must include) are of several kinds—faults and joints, bedding planes and lamination, and interbedded rock of other kinds. Are all these to be given equal value? Can anyone suggest possible limits for the abundance or extent of these openings which may be used to define a certain class of coal? The other criteria for judging weathering show a similar incapacity for quantitative expression. Mr. Campbell passes over this point to say "independent observers may place a certain coal in different groups—since there are no sharp lines of division between the groups." He has drawn *no line at all,* and I hardly think any committee or convention of authorities would be inclined to set up a standard of that sort. The properties are too indefinite. Any and all classifications of coal must show gradation between types, and it is impossible to criticize the fact of gradation; but it seems as if there might be some objection to using, as criteria for a classification, qualities almost incapable of quantitative expression.

In field work, where Mr. Campbell finds the method useful,

it has two defects, one of which—the personal equation—he recognizes but does not consider serious. The other must always be the lack of definite information as to the circumstances of weathering. The development of a plate-like structure, for example, must certainly be a function of the unknown time of exposure, and probably of all the variable qualities of climate in addition. There seem to be too many unknown factors for this system to be of more value than the former practice, *i. e.,* naming a coal from its physical behavior when charged into a locomotive or other fire box. This is above all others a practical method, and can hardly be stated in figures or quantities, on account of the variety of fire boxes. However, although it has this advantage in common with Mr. Campbell's proposal, it has an advantage over his, in that the name a coal receives is the net result of averaging the opinions of a great many practical men (the men who use it), rather than depending on a few who simply look it over.

The basis of classification depending on chemical tests is, however, capable of such expression in exact terms, and it is seldom that a bed of coal gets a prominent place in the market without an ordinary analysis, which can be used as that basis. Mr. Campbell thinks the ultimate analysis too slow and expensive for a practical man, but if a sample sent to him for report had to be weathered before it was classed, the time and expense would surpass anything now attempted. So, from the standpoint of the laboratory worker, the method is as unnecessary as it is to the practical man in the field.

Furthermore, if a proximate analysis is at hand it is not necessary to add a complete ultimate analysis to determine the exact character of the coal, but simply a determination of total carbon —a relatively easy and brief process. The classification recently suggested by the writer (this journal) was given out with the idea that this more accurate laboratory work need not be exceedingly complex or expensive. The names of the groups as found in that paper, and the limits of such groups, may be changed if the leading workers see fit. Mr. Campbell reports that a con-

ference of geologists of the United States Survey have agreed to drop the term "black lignite" and adopt "sub-bituminous" with new definition. This would alter the classification proposed, placing "black lignite" and probably some of the "low grade bituminous" in a new class to be known as "sub-bituminous" hereafter. However, the method of classification there proposed, based on total carbon and fixed carbon of the pure dry coal, may well be retained by laboratory workers and others, unless as Mr. Campbell states, it fails to conform to the facts and at the same time have a scientific basis. Although he makes this statement he fails to present any fact that the classification will not conform to and he makes no evident attempt to show a lack of science in its basis.

FRANK F. GROUT.

MINNEAPOLIS, MINN.,
June 1, 1908.

REVIEWS

Report on Gold Values in the Klondike High Level Gravels. By R. G. McConnell. Pp. 34. Geological Survey of Canada, Ottawa, 1907.

In 1905 the Geological Survey of Canada published a report by Mr. McConnell on the general geology and gold-bearing gravels of the Klondike district. The present report deals principally with the value still remaining in the Beach and Creek gravels and especially in the important high level deposit known as the White Channel gravels. The auriferous gravels are classified as follows:

Low level gravels	Gulch gravels.
	Creek gravels.
	River gravels.
Gravels at intermediate levels	Terrace gravels.
High level bench gravels	Klondike gravels.
	White Channel gravels.

The White Channel hill gravels are the oldest, and, excepting the present Creek gravels, the most important, economically. They represent remainders of old creek gravels probably deposited in a small local stream. They are traceable from the present mouth of Bear, Hunker, and Bonanza creeks far out into the present valley of the Klondike. An uplift of 700 feet allowed the streams to cut through the gravels of the White Channel and down into the bed rock to a depth of from 150 to 300 feet. The undestroyed portions of the older gravel form the White Channel gravels. The thickness of these quartzose well washed gravels ranges up to 150 feet and the original width from a couple of hundred yards to over a mile. Very slow deposition and easy grades probably characterized their deposition, which took place in a milder climate than that of the present time. The age is probably pliocene.

Careful sampling of the whole thickness shows that in a characteristic section the values in the lower four yards, including a foot of bed rock, average $2.15 per cubic yard, while those in the upper forty-six yards average less than two cents per cubic yard. The decrease is almost constant, except at one point 45 feet above the bed rock, where a slight enrichment occurs. In fact the first two yards on the bed rock average $4.13, the next two only 18 cents, while in the fifth and sixth yards the

values have decreased to five cents per cubic yard. At the top the value is only slightly above one cent. Where the slight enrichment takes place high above the bed rock the gravel is only a few inches thick and rests on a false bed rock of clay. Exceptionally the zone of maximum richness may be found from 3 to 12 feet above the bed rock. The concentration of all of the coarse and much of the fine gold near the bed rock can only be explained on the assumption that the gravels have been worked over several times by the stream.

The fineness of the Klondike gold is low, ranging from $12.50 to $17.50 per ounce. Some evidence is adduced tending to show an enrichment of the nuggets by dissolving from the fine 5 to 7 per cent. of the silver near the surface.

The report closes with the following summary, interesting in view of the recently proposed working of the remaining Klondike gravel by an American Company.

The total production of the camp (probably including 1907) is estimated at $119,000,000 in gold and $793,000 in silver.

ESTIMATED VALUES IN LOW LEVEL GRAVELS.

	Estimated Future Output.	Estimated Past Product.
Eldorado Creek.....	$2,600,000	$25,000,000
Upper Bonanza Creek	3,225,000	15,500,000
Lower Bonanza Creek	11,500,000	11,000,000
Klondike River Flats	6,500,000	1,000,000
Bear Creek	600,000	1,000,000
Hunker Creek	7,500,000	14,000,000
	$31,925,000	$67,500,000

ESTIMATED VALUES IN HILL GRAVELS.

Upper Bonanza and Eldorado Hills	$8,213,532	$24,000,000
Lower Bonanza Hills	7,528,720	750,000
Klondike River Hill	956,000	Small.
Hunker Creek Hills	5,019,370	2,500,000
	$21,717,620	$27,250,000

This estimate does not cover the creeks on the Indian River slope, such as the Dominion, Gold Run, Sulphur, and Quartz creeks. These are estimated to have produced $24,250,000, making the total production of the camp to date $119,000,000. A production of from eight to ten million dollars may still be expected from them.

The figures of Mr. McConnell correspond approximately to those of the engineers of the Yukon Gold Mining Company. It should be noted in closing that a prominent mining journal has recently published

editorial comments deprecating strongly the idea of governmental appraise of values of the gravels and also suggesting that the work was done too hurriedly. Regarding the first question there may be differences of opinion, but regarding the character of the work, Mr. McConnell's ability and intimate acquaintance with the district gives assurance that the figures are reliable.

W. LINDGREN.

Los Yacimientos de Boratos y otros productos minerales explotables del Territorio de los Andes. By DR. FRITZ REICHERT. Annales del Ministerio de Agricultura. Seccion Geologia, Mineralogia y Mineria, Tomo II., No. 2, Buenos Aires, 1907, pp. 104, with maps in pocket.

The author of this bulletin, a technical chemist, was employed by the Argentine government to investigate the saline and other deposits in the extreme northwestern corner of the republic where it borders against northern Chile and Southern Bolivia in the provinces of Atacama and Jujuy.

The most important of these deposits are the borax beds in the high plateaus of the Andes. They occur as "playa" deposits in dry lake basins at high altitudes of from 10,000 to 13,000 feet, principally in Atacama province and generally in volcanic regions, though one of them is surrounded by hills of gneiss and crystalline schists. The City of Salta, about 100 miles distant, is the nearest railroad point. Seven borax beds are described and mapped. Of these only two—those of Caurchari and Salinas Grandes are worked at present. At the latter place the property of Tres Morros is extensively exploited by a Belgian company. The valuable mineral is in all cases a boro-natro-calcite with about 8 per cent. soda, 12 per cent. lime, 30–40 per cent. boric anhydride, 30 per cent. water, and some sodium chloride. The latter product is leached out with water, and the remaining material is dried and calcined in revolving furnaces in order to eliminate the water. The material usually lies at the surface, or is at most covered by an efflorescence of salt, in beds of an average thickness of one meter and are usually underlain by clays and sands. The area covered is in some cases large. The borate usually occurs in these beds in rounded and rather pure lumps called "papas." The formation of the boro-natro-calcite is, according to the author, due to the reaction between gypsum and borax solutions, the latter being derived from volcanic sources.

In 1904, 3,700,000 kilograms of borate of calcium were exported by the Belgian Sociedad International de Borax at Tres Morros and from the beds at Caurchari.

The major part of the borax beds exploited in Chile and in the United States belong to the Anglo-American Consolidated Borax Company,

which dominates the markets of the world. On the other hand, most of the factories which make boron compounds have united into a single company, the Borax-Union. The Argentine borate is not controlled by the trust and sells at a somewhat higher price than that fixed by that association. The price of Argentine product with 44 per cent. boric anhydride is £8 per ton at Hamburg.

The author also describes some soda beds in the province of Atacama, consisting chiefly of carbonate and sulphate with some admixed chloride.

Further, several sulphur deposits are mentioned, but with one exception they occur at elevations of 15,000 or 16,000 feet in the craters of extinct volcanoes and have probably little economic value.

Recognizing the desirability of the establishment of sulphuric acid manufacturies in the republic the author finally describes a large deposit of somewhat cupriferous pyrite occurring in clay slates near the Bolivian boundary at Cerro Acay. He believes the acid could be profitably used for the local manufacturing of boric anhydride at the borax beds.

W. LINDGREN.

Transvaal Mines Department. Report of the Geological Survey for the year 1906, pp. 140. Pretoria, 1907.

The scheme of work reported in this volume was sanctioned in 1906 by the Commissioner of Mines and forms part of the general plan adopted for the geological mapping of the Colony. The staff consisted of H. Kynaston, Director; and E. T. Mellor, A. L. Hall and W. A. Humphrey, geologists. The colony is to be covered by quadrangles, each of which embraces approximately one degree of longitude by half a degree of latitude; of these about six are completed, chiefly near Johannesburg, Pretoria and Lydenburg. The report is accompanied by 37 plates and some figures.

The geologic maps are on the scale of approximately two and one-half miles to the inch and are well engraved. As usual in English colonies the topographic base consists of the cadastral maps without any indications of relief. This is of course a serious drawback. According to the experience in the United States Geological Survey a rough contouring with say 200 feet intervals could be effected with but slight addition to the cost by members of the geological field party, and this certainly would give the work a much greater value. The sections have been printed on a scale considerably larger than necessary. The report contains many interesting reproductions of photographs. It may be of interest to note that the total amount spent on the Survey in 1906 was only $32,500, of which about $5,000 represents traveling expenses.

The report contains the following papers:

(*a*) On the Southern Portion of the Area Occupied by the Pretoria-Johannesburg Granite, by H. Kynaston.

(*b*) The Geology of the District about Haenertsburg, Leydsdorp and the Murchison Range, by E. T. Mellor.

(*c*) The Geology of the Central Portion of the Middelburg District, by E. T. Mellor.

(*d*) The Geology of the Central Portion of the Lydenburg District, Between Lydenburg and Belvedere, by A. T. Hall.

(*e*) On Portions of the Lydenburg and Carolina Districts, by W. A. Humphrey.

(*f*) On a Portion of the Bushveld, South of the Rooiberg and East of the Crocodile River, by W. H. Humphrey.

(*g*) The Pretoria Series, Southeast of Rustenburg, by W. A. Humphrey.

(*h*) The Magnesite Deposits of Malelane, by A. T. Hall.

Mr. Kynaston's paper deals with the large area of granite immediately north of Johannesburg; its relations to the Witwatersrand Series are investigated and Dr. Corstorphine's conclusions confirmed that the quartzites are later than the granite. On the other hand, the granite is older than the sediments of the Swaziland System. According to this conclusion this granite can have had no direct influence on the genesis of the Johannesburg auriferous reefs.

The second paper by Mr. Mellor gives the results of a reconnaissance in the northern part of the colony of the Murchison and the Drakensberg Ranges north of Olifants River. The latter range reaches elevations of over 7,000 feet, while at its foot towards the sea extends the "low county" with an average elevation of 1,500 feet. The groups of rock represented are the Transvaal System, divided into the Pretoria, Dolomite and Black Reef Series, and the Swaziland System (Archean?) of crystalline schists and granites. The Drakensberg Range is largely formed by the resistant Black Reef quartzites, while the low county contains the crystalline rocks.

Economic interests center in the Murchison Range gold field, where, however, at the present time there is but little activity.

Climatic conditions and lack of water present great difficulties in the way of developing the mines. Only two prospects were actually worked in 1906.

The country rock consists of schists of the Swaziland System. The auriferous reefs occur in two parallel series, the more northerly of which is characterized by the presence of antimony ore.

There are three kinds of reefs: (*a*) Lenticular reefs, composed of quartz, in places with calcite or dolomite, distinct from the enclosing

schists and sometimes cutting across them. (*b*) Mineralized zones in talcose or chloritic schist, consisting of similar lenses, but intimately interleaved and merging in the country rock at the margins. (*c*) Black reefs or quartz schists with numerous bands of iron oxides. All these classes occur in both belts. The gold in class (*a*) is frequently coarse and accompanied by pyrite and stibnite. In the mineralized zones the gold is often invisible to the naked eye. Class (*c*) is regarded as an oxidized form of the others and it is believed that such reefs will become pyritic in depth.

In the Woodbush gold field close to Haenertsburg the granite contains several small normal quartz veins which have proved auriferous.

Entirely different types of gold deposits are the banket reefs near the base of the Black Reef quartzite in the escarpment of the Drakensburg Range. These reefs appear to be entirely similar to those of the Witwatersrand Series, though geologically of a younger age. The deposits are workable in places.

The paper by Mr. A. T. Hall on the geology of the central portion of the Lydenburg district contains many interesting features from an economic viewpoint.

The district described lies in the eastern part of the colony southward of the Olifants River and along the southerly continuation of the great Drakensberg escarpment. It is 200 miles east-northeast of Johannesburg. The rocks are mainly sedimentary and of the Transvaal System, embracing the Black Reef, Dolomite and Pretoria Series. The prevailing dip is westerly, at moderate angles. Along the eastern foot of the escarpment the Black Reef Series rests on the Swaziland granites and schists. Intrusions of sheets and dikes of diorite and diabase are noted chiefly in the Pretoria Series.

The most important mining developments occur at Pilgrims Rest, from where, next to the Rand, the greatest gold production of the Colony is obtained. The underground developments are considerable, especially at the Clewer mine where 600 natives are employed. This property yields the bulk of the production.

The auriferous deposits are bedded quartz veins which follow particular horizons in the Sedimentary Series, and which may, according to the author, be termed "ore-sheets."

Such reefs occur in the Pretoria Series and in the Black Reef Series; but the most important horizons found are in the dolomite series.

The Button Reefs in the Pretoria Series occur in thick beds of shale which underlie intruded sheets of amygdaloidal diabase. The yield is stated to be $4.00 per ton with a thickness of 14 inches. The ore is reduced in a 30-stamp mill.

Bevets Reef lies 250 feet above the base of the Pretoria Series between Carbonaceous shale and quartzitic sandstone; its width averages 18 inches. Immediately below lies a bed of conglomerate, 4 feet thick, which apparently is not auriferous, and underneath this is found a thick sheet of intrusive rock.

At Pilgrims Rest the cherty dolomite of the Dolomite series contains two important deposits called the Theta (upper) and Beta (lower) reefs, which persist in the same horizon over a distance of many miles. Their position is 100 and 300 feet below the base of the Pretoria Series. Sheets of diabase also follow the horizon persistently. The Clewer mine is working on these deposits, which sometimes reach 5 or 7 feet in thickness, and average from $9 to $13 per ton. The ore consists of quartz with some pyrite and in places a little chalcopyrite, but the deposits are oxidized deeply below their outcrops. The views of the author as to genesis are not very definite, nor does the paper contain a detailed description of the ores; he believes, however, that the deposits originated after the deposition and consolidation of the sedimentary beds and also previous to the intrusion of the system of dikes.

The Black Reef series contains a few thin interbedded quartz veins in the shales, but not in the quartzite. A few unimportant alluvial diggings are found in the district.

The persistent tendency of the deposits to form bedded veins is notable in connection with what is known of the Witwatersrand and other districts in the Transvaal. More detailed investigations will have to be undertaken before their genesis can be satisfactorily explained.

On the whole, the present volume is distinctly creditable to the Geological Survey of the Colony. W. LINDGREN.

Lead and Zinc in the United States. By WALTER RENTON INGALLS. Pp. x + 368, 3 plates, numerous small figures. New York, Hill Publishing Co., 1908.

This work, which comprises an economic history of the mining and smelting of the metals and the conditions which have affected the development of the industries, was prepared at the request of the Carnegie Institution of Washington, and with its assistance. Short descriptions are given of the occurrence of the ores and of their treatment but in the main the work is historical. It brings out clearly the essentials of the development of the industry and traces the influence of such factors as the development of transportation agencies, improvements in treatment, changes in tariff, etc. Both in general and in detail the work is excellently done and the author is to be congratulated upon having so successfully covered this field.

H. FOSTER BAIN.

Annual Report, Volume XVII., 1906, Iowa Geological Survey. Quarry Products, p. 622.

This report which appeared in print this year presents a diversity of topics and consists of the following divisions: "Mineral Products in Iowa for the year 1906," by S. W. Beyer; "Materials and Manufacture of Portland Cement," by S. W. Beyer and Ira A. Williams; "Physical Tests of Iowa Limes," by S. W. Beyer; "Selection of Power Plants and Equipment for Stone Quarries in Iowa," by G. W. Bissell; "The Geology of Iowa Quarry Products," by S. W. Beyer and Ira A. Williams; "Analyses of Iowa Coals, Limestones, Chalks, Clays, Shales and Marls; Tests of Iowa Building Stone," by A. Marston; "Directory of Iowa Limestone and Sandstone Quarries."

From the statistical part we learn that the total mineral production of Iowa for 1906 represented a valuation of $16,400,000. The distribution of the plants is shown on an excellent geological map.

In the chapter on cement materials and manufacture, the technology of Portland cement is treated in an excellent compilation, though some errors have crept in. For instance, on page 41 we read that "magnesia does not combine with silica and alumina at the clinkering heat employed," a statement which is not correct. The grinding of the raw materials is not discussed as clearly as might have been desired. In the discussion of the chemistry of Portland cement the statement is made that under oxidizing conditions the calcium sulphate dissociates into calcium oxide and sulphur trioxide. Unfortunately for the cement manufacturer this reaction is not quite so simple. Likewise, the increase in alumina and iron does not necessarily produce weak cements; the question is one bearing upon constancy of volume rather than strength. The criticism of a certain method of cement mixture calculation which happens to be used largely in practice (page 89) is not justified by the reasons given, especially since the writers admit that they have done no work along these lines.

The chapter on lime is quite complete and the many tensile strength tests of lime mortars made by the Survey are interesting and timely. Some attention might have been paid to the rate and completeness of hydration of different limes for the benefit of the various chemical industries employing lime.

Whether or not a chapter on power plants may be considered a proper subject for treatment in a Geological Survey report might be questioned by some.

The bulk of the volume treats of the geology of quarry products and appears to be an excellent presentation of the Geological conditions in the quarries of each county. The subject affords a fine oppor-

tunity for study and the writers have taken advantage of it. The illustrations are good.

In assembling the analyses of all the Iowa mineral products reference to these data has been made convenient.

In the chapter on the testing of building stone the results are arranged in tables and include the crushing and transverse strengths, absorption and freezing tests.

The volume reflects credit upon the activity of a state survey.

A. V. BLEININGER.

The Geological Relations of the Scandinavian Iron Ores. BY PROF. HJALMAR SJÖGREN, Ph.D. Trans. Am. Inst. Min. Engrs., Vol. 38 (1907), 1908, pp. 766–835.

Economic geologists will appreciate the comprehensive survey of Scandinavian iron ores given in English by Professor Sjögren, of Stockholm, in the *Transactions of the American Institute of Mining Engineers*. By comparing the several classes of deposits with one another and with similar deposits in the United States, many of which Professor Sjögren has seen, there is conveyed to the American reader a better understanding of the geological and commercial features of the Scandinavian iron ore situation than he is likely to get from detailed descriptions of different ores or districts. Professor Sjögren's classification is primarily neither genetic nor based on the age of the ores, but is based on age, lithology, relations to wall rock, genesis, etc. This frank recognition of the difficulty of logical classification in the present state of knowledge clears the ground for a lucid statement of the facts. As the article is itself a summary, the following summary and review, containing liberal quotations, will be confined to such points as seem to the reviewer to be of especial interest.

I. *The Ores of the Archean Crystalline Schists.*—These ores belong to the division of the Archean formation, crystallized in the anamorphic zone and interwoven with granites; the ores occur associated with ortho and para gneisses, granulites and dolomitized or silicified limestones. Taking into consideration all the chemical and geological characters of the ores, H. Johansson has arranged the different ore-types in the following order: apatite ores, quartz ores rich in alumina, quartz-banded ores, *skarn* ores and ores with limestone. (*Skarn* is the Swedish name for rocks of varying composition, mostly consisting of lime, magnesia, iron and alumina silicates of the pyroxene, amphibole and garnet groups; as secondary minerals, epidote, chlorite, biotite and talc occur. The *skarn* is scarcely an independent rock but is connected with the ore-deposits. It is formed through an interchange between the silica of the quartz feldspar rocks and the basic constituents of

the ore formation.) Owing to the absence of phosphorus and to other excellent qualities characterizing some of these ores, they were for centuries the only ores that were mined in Sweden, and they have been the raw material of the Swedish iron that has won world-wide renown. These ores occur especially in Sweden, but also in certain parts of Norway.

For the most part the ores of this group, typically the banded siliceous and *skarn* ores, are regarded as metasomatic replacements of preexisting rocks under deep-seated anamorphic conditions, not in open channels, either by magmatic waters carrying ore or by small amounts of water already in the rocks deriving their ore by concentration from the surrounding rocks. Near the surface the ores have suffered secondary alteration of the katamorphic type. Against their sedimentary origin are urged the following arguments: (1) The surrounding rocks are igneous. (2) The form of the deposits is not that of sediments. In general they are more irregular than is consistent with sedimentary deposition. The form of the deposits is regarded as partly original, due to association with igneous rocks, and partly the result of secondary deformation. (3) The banded structure, which might be regarded as sedimentary, is in some cases a schistose structure, and in the quartz banded ores the structure may be the result of secondary alteration.

Certain of the ores are so closely related to pegmatites as to suggest genetic connection with them. Coarsely crystalline magnetite is often found in the pegmatite veins, indicating that the aqueo-igneous solutions giving rise to the pegmatite originated from the same source as the iron ore. On the other hand, in certain of the contact deposits and especially contacts of limestones and igneous rocks, the situation of the ores along the contact can hardly be explained by assuming them to be of primary origin; the only explanation possible is that the ores have been precipitated along the contact from ferriferous solutions.

Some of the ores, illustrated by those of the Grängesberg and Norrbotten deposits, differ from the others of this group and their characteristic properties seem to be most satisfactorily explained by assuming them to be transformed basic segregations in gneiss-granites (orthogneisses).

The katamorphic changes which the ores of Group I. have undergone at the surface include the formation of chlorite, talc, epidote, silica and calcite from the original pyroxene and amphibole. Banding is sometimes lost. Iron is concentrated by leaching of silica and by deposition of iron oxide in the openings. Hematite is locally changed to magnetite for reasons not apparent, although it is suggested that organic acids or alkaline solutions proceeding from the silicate rocks

may be factors in the change. Locally hematite developed from magnetite.

Professor Sjögren regards the apatite ores of Group I. as typically represented by the ores of the Mineville group in the Lake Champlain district of New York. The ores rich in silica and alumina correspond to the pegmatites of New Jersey. The quartz-banded siliceous ores recall many ores of the Lake Superior region and especially the Archean ores of the Vermilion district. The *sharn* ores have their equivalents in the Archean deposits of the Tillie Foster Mine of northern New York, in ores of Pennsylvania, and especially in the Cranberry ores of North Carolina. The ores associated with the limestone are compared with ores at Franklin Furnace, New Jersey, and with certain Ontario ores.

If the ores of this class are essentially developed in the deep-seated zone of anamorphism, as held by Professor Sjögren, this origin seems to require emphasis on their primary introduction by hot solutions. The alternative suggested by Professor Sjögren, that they are concentrated from the surrounding rock by water already contained in them, would call for a degree of segregation and transportation which has not yet been shown to be effective in the zone of anamorphism, where the conditions of rock flowage are not favorable to rapid circulation and where the changes are characteristically in the direction of mixing substances and developing complex minerals rather than the segregation and simplification necessary to the development of iron ore deposits of simple composition. The hypothesis of the development of the ores under surface conditions by sedimentation does not seem to be favorably regarded by Professor Sjögren. He does not discuss the possibility that the ores may have resulted from katamorphic processes, other than those involving sedimentation, rather than from anamorphism, and subsequently anamorphosed.

II. *The Ores of the Porphyries* (keratophyres), belonging to a division of the Archean formation, plicated in pre-Cambrian time, but younger than the old granites. The ores of Group II. could not for a long time be utilized on acount of their high percentage of phosphorus; moreover, the situation of the deposits in the extreme north of the Scandinavian peninsula discouraged mining enterprises. Some of the deposits of this group, such as that of Kiirunavaara, are among the greatest in the world. Thanks to the basic refining methods, they have now gained great importance, and are more and more utilized for the Swedish iron industry; having, however, as yet chiefly given rise to an ore export on a large scale. The ores of this group occur only in Sweden. The ores contain primary apatite and other minerals and exhibit schlieren of different kinds of ore, taken to represent original

flow structure. Near the contact the ore contains abundant fragments of porphyry, largely altered to amphibolite and chlorite.

The genetic connection of these ores with the porphyries is so manifest that it has been admitted by all who have expressed an opinion on the subject. The ore is regarded as having solidified from an iron-alumina-silicate magma intruded as a vein between the porphyries, followed by pneumatolitic agencies, especially along the contact, resulting in the uralitization of the amphiboles, in the development of martite and specular hematite, the leaching of pyrite and apatite, the formation of porous ore containing calcite, and accumulation of apatite near the footwall. But while at Kiiruna the magmatic characters of the ore mass are most marked and the pneumatolitic characters subordinate, at Mertainen the reverse is the case. Högbom has given a theoretical exposition of the formation of ores of this kind. He starts from an iron-alkali-silicate magma composed, approximately, in the proportion of one molecule or orthoclase, one molecule of albite, and one molecule of magnetite. Such a magma differs in composition from known and common magma-types only by containing a little more ferric oxide and a somewhat smaller amount of lime and magnesia. As, at the solidification of such a magma, the larger part of the iron must segregate as magnetite, because, owing to the absence of lime and magnesia, it cannot combine with the silica, the differentiation of two rocks, one chiefly consisting of magnetite, the other of feldspar, is easily accounted for. Högbom, therefore, holds that the alkali-silicate magmas rich in iron, to which petrography has as yet paid but little attention, have a just claim to a place in the system, and that their most typical representatives are magnetite-bearing syenitic rocks of this kind.

These deposits are compared with the iron ores of Iron Mountain, Missouri, and possibly with the Durango and Las Truchas deposits of Mexico. The reviewer would also suggest comparison with the iron ores of southern Utah, though the genesis of the latter is not entirely parallel to that here outlined.

III. *The Ores of the Basic Eruptive Rocks,* occurring as differentiations in intrusives of diabase, gabbro and norite, forming stocks, bosses or laccolites within schists of Archean and Silurian age. The ores of Group III. are chemically characterized by a high amount of titanium, which makes them very difficult to reduce. They have hitherto been made use of on a very small scale only. Vast deposits of them occur in both Sweden and Norway. Though the rocks which inclose the deposits of this class differ in composition (as real gabbros, norites, diabases or nepheline-syenites), as well as in age (some of them belonging to the oldest Archean formation, and the youngest dating from post-Silurian time); yet a marked degree of basicity seems to be a necessary

condition for the formation of such concentrations. Vogt puts the highest acidity at 57 per cent. SiO_2. The majority of the deposits occur in rocks with a silica percentage of from 48 to 54 per cent. A remarkable feature of the ore concentrations in question is their occurrence, almost without exception, in the central parts of the eruptive masses. This gives them a character different from that of those concentrations of basic constituents in an eruptive rock which are often met with along the margins of rock veins, and in which the enrichment has not proceeded so far as to form an iron ore. It seems as if, with respect to this kind of segregations, the view according to which the magma is regarded as a mixture of different liquids, partly insoluble in one another, were decidedly preferable to the theory which considers the laws of dilute solutions applicable to the magma.

IV. *Ores Occurring in the Metamorphosed Cambro-Silurian Schists,* chiefly in the mica-schist group, characterized by mighty beds of limestone. The ores of Group IV. occur only in the metamorphosed Silurian formations of Norway. They are characterized by a comparatively low percentage of iron, and have not as yet been utilized for the Scandinavian iron industry, but preparations are going on for mining and exporting them on a large scale after subjecting them to magnetic concentration. These ores are therefore almost exclusively confined to the Norwegian coast and the valleys penetrating into the country from the sea. They are sediments of shallow water deposition. They belong to a ferriferous formation of vast horizontal extent, occupying nearly the same geological horizon in the series as the mica-schist-marble member of this sedimentary series. The connection with the limestone is so strongly marked that in certain districts nearly every limestone bed is accompanied by iron ore; some observers have even been inclined to assume a connection between the thickness of the limestone beds and the size of the iron ore deposits. Whether these ores are primary sedimentary deposits or secondary concentrations of leaner iron-bearing formations is still an open question of the greatest practical importance. As to the depth which the ores of this kind reach, there is as yet no practical experience, as neither exploratory work nor even any borings below the present or former groundwater level have been performed. As compared with the Archean ores, interchange of constituents between the schists, the iron ore and the limestone, lying close to one another, has been rather limited. Probably also the submersion in the anamorphic zone did not go so deep as to reach a temperature high enough for the formation of anhydrous silicates on a large scale. The depth and the temperature under which the crystallization of these ores occurred seem to have been better adapted to produce the slightly hydrated silicates of the epidote group.

The transformations in the katamorphic zone also are less marked; one finds no concentrations of so great richness, no "sköl" formations, and no accumulations of ores in pitching troughs or on impervious basements. The ores are of more equal leanness, and in general the concentration does not exceed 40 per cent. of iron.

On the whole, one may consider these deposits as the roots or the deepest, comparatively unconcentrated parts of regional metamorphosed chemical depositions, laid open by the deeply penetrating fjords and valleys of the Norwegian coast; the upper, probably more concentrated and richer parts of the same deposits, having been destroyed by erosion.

The ores of this class are compared with the Clinton ores of the Lower Silurian of the Appalachians of the eastern United States, though, of course, the Clinton ores are less metamorphosed.

V. *Contact Formations Connected with Acid Eruptive Rocks* of post-Silurian age, in the Archean gneisses and in the Silurian limestones and argillaceous schists of the Christiania basin. They are of no practical importance. The iron ores are, as a rule, mixed with true contact minerals, such as different species of the garnet and vesuvian groups, scapolite, wollastonite, and others. They are high in sulphur.

These are compared with deposits of a similar kind in Colorado and California where they are associated with the younger eruptives.

VI. *Lake and Bog Ores,* belonging to the most recent geological period. On account of their cheap exploitation and easy reducibility, they were earliest raw material of iron manufacture in the Scandinavian countries; but their importance has been decreasing as the iron manufacture has become a great industry. They occur only sparingly in the regions covered by glacial and post-glacial marine deposits, such as the lower coast belt of southern Sweden, and the plains surrounding the great lakes of Vänern, Vettern, Hjelmaren and Mälaren. In short, the lake and bog ores are most frequent above the marine level of the glacial period. A certain connection with the distribution of the peat-mosses is indicated.

The reader will note similarities in the origin ascribed to the ores of classes II. and V. and to part of the ores of class I., and possibly also between other classes, suggesting that the strict genetic classification would have fewer subdivisions than the one here used; in other words, that in successive geological periods substantially the same variety of factors in the production of iron ores has been repeated, though with variable relative range. The development of knowledge of North American iron ore deposits seems similarly to trend toward ascribing essentially similar agencies to the development of ore deposits in each

of several geological horizons of North America, although, due to difference in later alterations, the superficial differences may be marked.

C. K. LEITH.

Geology of the Adirondack Magnetite Iron Ores. By DAVID H. NEWLAND. With a Report on the Mineville-Port Henry Mine Group by James F. Kemp. New York State Museum Bulletin 119, April, 1908, 173 pp. Illustrated by maps, diagrams and half-tones. See also ECONOMIC GEOLOGY, Vol. II., No. 8, p. 763.

The bulletin is divided into three parts. Part I. (14 pp.) is descriptive of the geography, physiography and geology of the region. It also contains a geological map of the region and a brief summary of the principal publications on the geology of the Adirondacks.

Part II. (123 pp.) is devoted to the nontitaniferous magnetites and contains a report by Professor Kemp on the Mineville-Port Henry Mine Group. As Mr. Newland states, the term "nontitaniferous" is somewhat of a misnomer, as all of the so-called nontitaniferous ores contain titanium. The term is used for low titanium magnetites carrying a proportion of the element too small to have any notable influence on their metallurgical behavior. These ores are the most widespread of the Adirondack ores and have been worked at a great number of localities, furnishing a total of 35,000,000 tons of iron ore.

The ores vary widely in composition. In iron content they range from practically pure magnetite to the lowest grade of milling ore worked, which carries about 35 per cent iron. On the basis of phosphorus content the ores are divided into low phosphorus, Bessemer, and non-Bessemer grades. Phosphorus occurs in apatite and its percentage is reduced by magnetic separation. The alteration of the magnetite to hematite is briefly mentioned and it is to be regretted that more attention was not given to this very interesting metamorphic problem.

The ore bodies are generally of tabular or lenticular form believed to be conditioned by the structure of the enclosing rocks. From this fact the author argues that the ore bodies were deposited before the rocks received their present structural arrangement and consequently have passed through all the vicissitudes of pressure and deformation that have been impressed upon their walls. The wall rocks include gneisses of granitic, syenitic and dioritic composition, acid pyritic, garnetiferous gneiss, hornblende, and biotite schists, amphibolites, and occasionally crystalline, limestones. The author divides these into (1) igneous derivatives and those closely allied to the characteristic intrusive masses of the Adirondacks; (2) members of the sedimentary or Grenville group.

In discussing the origin of the nontitaniferous magnetites reference

is made by Mr. Newland to the conclusions reached by Prof. Kemp as a result of detailed study of the geographical surroundings of the magnetites, previously published. The existence of igneous masses in the vicinity and the evidences of their agency in the formation of many of the accompanying minerals led Prof. Kemp to support the view that the ores were related to the intrusive rocks. As a result of additional knowledge relative to doubtful points in the geology of the district Mr. Newland arrives at the interesting conclusion that the more immediate source of the ores is the augite syenite. He believes that the ores have formed by igneous action and are related to the wall rocks just as the titaniferous magnetites are related to the gabbros and anorthosites. As to the exact nature of the genesis of the ores the text is not entirely clear. Magmatic differentiation is ascribed as a prominent factor in the early stages of the formation of the ores and as a possible explanation of the whole course of their development. From the nature of the minerals accompanying the ores Mr. Newland infers that the effects of highly heated vapors and hot magmatic waters have been important in producing the final results. He believes that these agencies would be especially active in the final stages of cooling and consolidation of the rock walls, and in some cases may have been the determinative factors in bringing the iron minerals into their present position. The ore bodies thus formed would be comparable in a way to pegmatite dikes.

In support of his belief in the efficacy of magmatic differentiation as applied to the formation of ore bodies in acid rocks the author makes the interesting statement that the relative acidity of the rocks is not so important as the relation between the iron and lime-magnesia contents. With a large excess of iron over the amounts required to form augite, hornblende and biotite, the segregation of iron oxides might well be expected. This is exactly the condition presented by the wall rocks of the ores. A series of chemical analyses are given to show that the acid intrusives carry relatively high percentages of free iron. The amounts of magnetite calculated for the rocks, all of which are from localities outside of the mine districts, run from 1.58 to 6.57 per cent. Higher percentages would undoubtedly be found in specimens taken from the actual wall rocks. With five or six per cent. of magnetite it is calculated that a concentration of ten to one would produce the leaner ores that are mined in this region.

An explanation similar to the above, of the segregation of magnetite from acid magmas, has been made by Högbom and is referred to by Professor Hjalmar Sjögren in his article "The Geological Relations of the Scandanavian Iron Ores," *Trans. Am. Inst. of M. E.*, Vol XXXVIII., 1907.

The difference in titanium content between the ores associated with the granites and syenitic and those associated with gabbros and anorthosites is explained by the fact that in the silicious rocks the titanium is combined with lime and silica to form titanite which has been held mainly in the body of the rock mass, while in the basic magmas the silica has been entirely taken up by the feldspathic and ferromagnesian constituents and the titanium consequently united with the iron and has been segregated with it in the ore bodies. The ores in the acid rocks commonly contain a fraction of one per cent. or so of titanium in the form of titanite.

The remainder of part II. is devoted to detailed descriptions of the separate mine groups in which the history, geology, and economics of each group is discussed in considerable detail, with illustrations and accompanied by numerous chemical analyses. Professor Kemp's report on the Mineville-Port Henry mine group contains much that is of both economic and scientific interest.

Part III. (24 pp.) is given to a discussion of the titaniferous magnetites. Under this class are included the magnetic ores that carry titanium as an essential ingredient, averaging perhaps 15 per cent. in a majority of the ore deposits. The distribution of the titaniferous-magnetites is conditioned primarily by the occurrence of the gabbro-anorthosite intrusions. In the relations they bear to the enclosing rocks the ores are sharply differentiated from those of the nontitaniferous class, which occur in the sedimentary gneisses. They are themselves a magmatic differentiation of the igneous magma from which the walls have been derived. The author quotes Professor Kemp in support of this statement. No attempt is made to analyze the causes producing magmatic segregation.

An interesting but rather brief section is given to a discussion of the mineralogy of the magnetites. The titanium occurs as ilmenite and the relation of this mineral to the magnetite is well brought out in excellent photographs of etched surfaces of polished specimens.

Relative to the commercial utilization of titaniferous ores the author discusses the possibility of the reduction of the titanium content by crushing and magnetic separation previous to smelting.

The remainder of part III. is devoted to descriptions of the principal localities where titaniferous ore occurs.

WARREN J. MEAD.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

G. F. LOUGHLIN.

METALLIFEROUS DEPOSITS.

COPPER.

The Genesis of the Copper Ores in Shasta County, west of the Sacramento River. By W. FORSTNER. Min. and Sci. Press. Vol. XCVII., No. 8, 1908, pp. 261–262.

Ores thought to have been formed by a double process: (1) replacement of the quartz and feldspar of rhyolite by means of alkaline carbonates and CO_2; (2) replacement of alteration products by metallic sulphides by means of alkaline sulphides and H_2S. Formed in zones of intense fracturing.

GOLD AND SILVER.

Gold and Silver. By W. R. CRANE, Ph.D., Instructor in Mining. School of Mines, Columbia University. 8vo, pp. x + 727, illustrated. Cloth, $5.00 net. New York, 1908. John Wiley & Sons.

An economic history of mining in the United States; the geographical and geological occurrence of the precious metals, with their mineralogical associations; history and description of methods of mining and extraction of values; and a detailed discussion of the production of gold and silver in the world and the United States.

New Theory of Bed Rock Concentration of Gold. Editorial in Min. and Sci. Press. Vol. XCVII., No. 7, 1908, p. 201.

States the new conception of "glacial creep" in river deposits as competent to produce concentration of heavy minerals towards the bottom.

The Great Waihi Mine (New Zealand). By J. M. BELL. Can. Min. Jl. Vol. 29, No. 16, pp. 388–393; No. 17, pp. 420–424.

Outlines general physiography and geology, mentions details of principal veins, describes vein material, outlines theory of origin (pro-

pylitization of dacites, with later concentrations in open spaces), and concludes with descriptions of methods of mining, metallurgy, costs, and statistics.

IRON.

Association of Magnetite with Sulphides in Mineral Deposits. By J. B. HASTINGS. Min. and Sci. Press. Vol. XCVII., No. 10, 1908, pp. 333–334; No. 11, pp. 358–359.

Quotes and briefly discusses statements from various reports (mostly U. S. G. S. geologists) and offers suggestion that magnetite forms when the depositing solution contains insufficient sulphur to convert all the Cu and Fe present into sulphides.

The Origin of Bombshell Ore. By H. M. CHANCE. Can. Min. Jl. Vol. 29, No. 16, pp. 402–403.

Attributes origin of limonite geodes to oxidation of iron minerals disseminated or concentrated in ferruginous sediments, mostly as sulphide, less commonly as carbonate. Acids developed during oxidation of iron minerals serve to decompose and, wholly or partially, to remove rock material.

The Pyritic Origin of Iron Ore Deposits. By H. M. CHANCE. E. and M. Jl. Vol. 86, No. 9, 1908, pp. 408–410.

For most part, an argument that all important iron deposits (*e. g.*, Lake Superior Ores) in rocks of sedimentary origin result from oxidation of sedimentary deposits of pyrites (bog ore and oxidized outcrops of carbonates excepted). Last part chiefly a preliminary discussion of chemical reactions involved in the oxidation of pyrites.

NON-METALLIFEROUS DEPOSITS.

COAL.

Die Braunkohlenlagerstätten des Hohen Westerwaldes unter besonderer Berucksichtigung iher wirtschaftlichen Verhaltnisse. By F. FRIESE. Zeit. f. Prakt. Geol. XVI. Jg., 6 H., 1908, pp. 225–237.

I. Geologic-Technical Part: describes topography and hydrography, geology and mineralogy, the quality of the coal, mine development, former working, historic sketch, and present working.

II. Economic Part: deals with future and valuation.

The Occurrence and Commercial Uses of Fluorspar. By W. M. EGGLESTONE. Trans. Inst. Min. Eng. (Brit.). Vol. XXXV., Pt. 2, pp. 271–284, 1908.

I. Occurrence, etc.: chiefly a résumé of several English and American papers on occurrence, properties, associated minerals, and origin.

II. Commercial uses: chiefly résumé.

III. Weardale Fluorspar: description of the several veins of this district.

IV. Bibliography: Discussion by members of Institute.

REGIONAL REPORTS.

Die Erzlagerstätten von Cartagena in Spanien. By R. PILZ. Zeit. f. Prakt. Geol. Jg. XVI., H. 5, pp. 177–190, with Figs. 31–38, 1908.

I. Geographic and general geologic relations.

II. Ore Deposits: include (*a*) lead, zinc, and copper; (*b*) iron, with and without manganese; (*c*) tin. Forms of deposit are (*a*) veins in eruptive rock; (*b*) contact veins between eruptives, dolomite, and slate; (*c*) veins in slate both crossing and following bedding; and (*d*) bosses, pipes, and bedded masses in dolomite.

III. Development and present conditions of mining.

The Ore Deposits of Magdalena, New Mexico. By P. ARGALL. E. & M. Jl. Vol. 86, No. 8, 1908, pp. 366–370.

Brief historical sketch; general account of geology; positions and irregularities of ore deposition; paragenesis of the ores. Ore minerals contain silver, lead, zinc, copper and iron. They comprise primary mixed sulphides and a variety of secondary minerals.

GENESIS OF ORE DEPOSITS.

Diffusion as a Factor in Ore Deposition. Further discussion of paper by L. T. WRIGHT. Min. and Sci. Press. Vol. XCVII., No. 8, 1908, p. 250. Author replies to discussion by H. H. Knox and argues against Soret's principle as an explanation of certain ore bodies.

Mechanics of Igneous Intrusion (Third Paper). By R. A. DALY. Amer. Jour. Sci. Vol. XXVI., 4th Ser., 1908, pp. 17–50.

Continues discussion of "stoping hypothesis" of batholithic intrusion, introducing the more significant, newer experimental results, answering criticisms, and concluding with certain important corollaries and tests of the hypothesis. Last portion includes origin of granite, the petrogenic cycle, and the origin of magmatic or "resurgent" water and gases. Comparison of data indicates that water and gases were occluded in assimilated sediments.

Mine Waters: Their Composition and Value. By A. C. LANE. Mining World. June 6, 1908, p. 899.

A brief preliminary discussion of mine waters highly charged with earthy chlorides occurring (1) in the older rocks and (2) at considerable depth.

Rock Pressure and Metamorphism. By H. M. CHANCE. Min. and Sci. Press. Vol. XCVII., No. 9, 1908, pp. 299–302.

Argues that pressure ("lithostatic," or superincumbent, and "arch-thrust") is more important than cementation in the consolidation of rocks, near surface as well as at considerable depth; but that some cementation is necessary before "arch-thrust" stresses can become of importance. Regards rock flowage and fracturing as due to "arch-thrust" rather than to "lithostatic" pressure and hence independent of fixed zones. Regards the interstitial water squeezed out of the compressed rocks as available for ore deposition in neighboring cavities.

Volcanic Waters. By J. B. HASTINGS. Trans. A. I. M. E. 1908, pp. 345–354. Abstract in Min. and Sci Press. Vol. XCVII., No. 7, 1908, pp. 229–231.

A digest of studies by several well-known geologists and physicists bearing on the question as to whether water in deeply buried oceanic sediments can make its way to the conduits of molten material.

SCIENTIFIC NOTES AND NEWS[1]

THE NINETY-THIRD MEETING of the American Institute of Mining Engineers was held in Chattanooga, Tenn., on the 1st of October and the days following.

It was originally proposed to hold this meeting in Birmingham, Ala., but owing to the labor conditions prevailing there at the time, the place of the meeting was changed to Chattanooga. Only a very short notice was given to the local committee and to those in Chattanooga who took charge of the entertainment of the members of the Institute, but the meeting, as a whole, was one of the most successful that has been held, and the entertainment accorded to those who were present was such as to leave a pleasant impression not only of the hospitality of the South, but also of the industrial possibilities which it held forth to the mining engineer in the future.

A number of interesting papers were read at the meeting of the Institute. Those which are of special interest to the readers of ECONOMIC GEOLOGY are that read by E. F. Burchard on the "Clinton Iron Ore in Alabama," and a paper by Mr. Charles Butts of the United States Geological Survey on the subject of Alabama coals. These two papers were designed to set forth the results of recent investigation by these two members of the United States Geological Survey on the Birmingham district, as the meeting was originally to have been held in that place. The fact that they were read at Chattanooga did not in any way detract, however, from their interest. Mr. Burchard estimates that the available ore left in the main portion of the Birmingham district is 351,149,500 tons. Dr. Burchard is of the opinion that

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

the Clinton Iron Ores are the result of original deposition and do not owe their value to secondary alteration.

Mr. Butts' paper included a discussion of the Plateau field, the Warrior field, the Coosa basin and the Cahaba basin. He estimates the total tonnage of coal in these fields at 59,826,968,000 tons.

Following the Chattanooga meeting, where the members of the Institute were delightfully entertained, a special train conducted the party to Ducktown, Tenn., where they were entertained by the Tennessee Copper Co. and had the pleasure of visiting the mines of that company and going through the sulphuric acid plant and smelter. The company had prepared a separate pamphlet for the visit of the Institute describing the mine, smelters and sulphuric acid plant, with the methods used in the different processes of treatment to which the ore was subjected.

THE VIRGINIA GEOLOGICAL SURVEY, recently established by the General Assembly of Virginia, with headquarters at the University of Virginia, is under the direction of a commission composed of Governor Swanson (chairman), President Alderman of the University of Virginia, President Barringer of the Virginia Polytechnic Institute, Superintendent Nichols of the Virginia Military Institute, and Hon. A. M. Bowman, of Salem, Va.

At a recent meeting of the commission Dr. Thomas L. Watson, Professor of Economic Geology in the University of Virginia, was elected director of the Survey. Dr. J. S. Grasty, of the Maryland Geological Survey, was appointed Assistant Geologist, and Mr. Wm. M. Thornton, Jr., of the University of Virginia, Chemist.

Work is in progress on the geology of the Coastal Plain region, including the underground water resources; cement and cement materials; topography and geology of the Virgilina copper district, geology of the rutile deposits; and building and ornamental stones. The studies of the Coastal Plain geology and topographic mapping of the Virgilina district are in coöperation with the United States Geological Survey.

AT NORTHWESTERN UNIVERSITY Dr. George R. Mansfield, of Harvard University, has been appointed Assistant Professor of Geology to succeed Professor J. W. Goldthwait, who goes to Dartmouth College. Professor Mansfield will begin work in February, 1909. Mr. C. E. Decker has been appointed instructor in Geology at Northwestern University for the first half of the present year, and Mr. D. F. Higgins, Jr., has been appointed to an assistantship, and Professor J. H. Cline, of Bridgewater College, Virginia, to a fellowship in the same department.

THE UTAH BRANCH of the American Mining Congress which has recently been organized, contemplates an attempt at the erection of a Mining Temple Building for headquarters in Salt Lake City.

A PUBLIC LECTURE was delivered before the New York Academy of Sciences on the 12th of October, 1908, on "The Volcano of Jorullo, Mexico; History, Features, Repopulation of the District by Animals and Plants." The lecture was delivered by Professor Hans Gadow, F.R.S., of the University of Cambridge, England, and was illustrated by lantern slides.

MEMBERS OF THE STAFF of the United States Geological Survey who have spent the summer in the field in various parts of the United States are returning to Washington for the winter. In places where climatic conditions have permitted continuance of work during the early winter, the geologists will not return to the Survey until the Christmas holidays.

Although the Survey appropriation was practically the same as in previous years, the amount of work accomplished in the past summer has increased over former years, owing to the greater efficiency of the men regularly employed and to the character of the temporary employers. The employment of college students as cooks and teamsters has effected a notable increase in the amount of work done, for these men are readily trained to assist in the geologic work and gladly devote what would be their leisure time to assisting in the scientific work of the parties. Those chosen from the numerous applicants for positions are, so far as possible, students who are taking geology as a part of their

college work. The field experience therefore is greatly beneficial to them in their understanding of the science as well as to the Survey.

MR. M. R. CAMPBELL, who is in charge of the investigation of the fuel resources of the United States carried on by the Federal Survey, has returned to Washington after spending the summer in the western states.

A RECENT PUBLICATION of the United States Geological Survey of interest to students of Economic Geology is Bulletin 348, entitled "Coal Resources of the Russell Fork Basin in Kentucky and Virginia." This report, which is by Ralph W. Stone, describes the occurrence of bituminous and coking coal in the mountainous region along the state line in the area drained by Russell Fork of Big Sandy River.

THE ECONOMIC GEOLOGY OF THE KENOVA QUADRANGLE forms the subject of a report by W. C. Phalen, of the United States Geological Survey, just issued by the Survey as Bulletin 349.

THE GEOLOGICAL SURVEY of West Virginia announces the publication of a volume on "Coal Resources" and an economic map of the state. The following description of these volumes may be of interest to the readers of ECONOMIC GEOLOGY.

1. New Coal, Oil, Gas and Limestone Map of the State issued under date of August 31st, 1908, showing in separate colors the Coal Formations, and also the Limestone Areas of the State. The principal Anticlinical Lines, as well as the developed Oil and Gas fields are also indicated by appropriate symbols. The topographic base of this map is entirely new and more accurate than that of any map of West Virginia heretofore published, having been reduced from the topographic sheets of the U. S. G. Survey. Also the location, name, and post-office address of every coal company in the State shipping coal by rail or river is printed by counties on the map which is larger than previous issues, being published on a scale of 7 miles to the inch. Price, either folded or rolled, postage paid by the Survey, 50 cents when ordered separately, but in combination, see below.

2. Supplementary Coal Report, Volume II (A) over 700 pages, issued under date of September 15th, 1908, with map showing location of bore holes, the records of which are given in the text. This Supplementary Coal Report devotes much more space than did the older Volume II to the region southwest from the Great Kanawha and New rivers, containing more elaborate tables of chemical analyses, both proximate and ultimate than ever heretofore attempted in any State Geological Survey Report. The revised correlation of the coals of the Kanawha series is also given in full, together with corrections of the errors made in the correlations attempted in Volume II. Published only in cloth binding, price $2.00, when ordered separately, or $2.35 with new Coal, Oil, Gas and Limestone Map, postage paid by the Survey. For other combinations at reduced price for all the other Survey Publications (Vol. I (A) Petroleum and Natural Gas, Vol. II on Coal, Vol. III on Clays, Limestones and Cements, and the Detailed County Report on Ohio, Brooke and Hancock Counties with its Atlas of Topographic Geologic and Soil Maps), write the office of the State Geological Survey, P. O. Box 448, Morgantown, W. Va., and ask for its descriptive circular.

AT A MEETING of the Section of Geology and Mineralogy and the New York Academy of Sciences, held at the American Museum of Natural History in New York on the 5th of October, the following papers were read:

"Revision of the Geology of Long Island" by Professor W. O. Crosby. "The Production of Low-Grade Copper Ore in the West" by Professor James F. Kemp. "Limestone Interbedded with the Fordham Gneiss of New York City" (illustrated) by Dr. Charles P. Berkey. "Continental Formation of the American Paleozoic" by Professor A. W. Grabau. "Note on the Fumaroles of Mt. Pelé, Martinique" by Dr. E. O. Hovey.

MR. S. F. EMMONS of the United States Geological Survey recently returned from the West. After arriving in Washington he visited New Haven, Conn.

D. B. DOWLING, of the Canadian Geological Survey, has been occupied during the past month with an examination of the coal deposits in the Edmonton District in Alberta.

A SMALL SMELTING PLANT of modern design, complete in all its details but of miniature size, has been erected in the Metallurgical Department of Stanford University, Palo Alto, Cal., for the use of the students. An electric smelter of the same design as that used in the Pit River Iron Mines has also been installed, in order that experiments may be conducted in the electric smelting of iron.

A CONVENTION OF MINING ENGINEERS and others interested in mines was recently held in Denver, Colo. A committee was appointed to undertake the organization of the Colorado Branch of the American Mining Congress, to be composed of a representative from each of the mining districts of the State. A meeting was appointed for the 14th of October. Each mining company of the State has been requested to appoint a delegate to serve on the committee.

IN THE SOUTH DAKOTA SCHOOL OF MINES a new Bulletin, No. 8, has recently been issued. It is a pamphlet of 56 pages in length and discusses the cement resources of the Black Hills. The authors are C. C. O'Hara, M. F. Coolbaugh, M. A. Ehle, Jr., and Charles H. Fulton.